G.E.C. Journal

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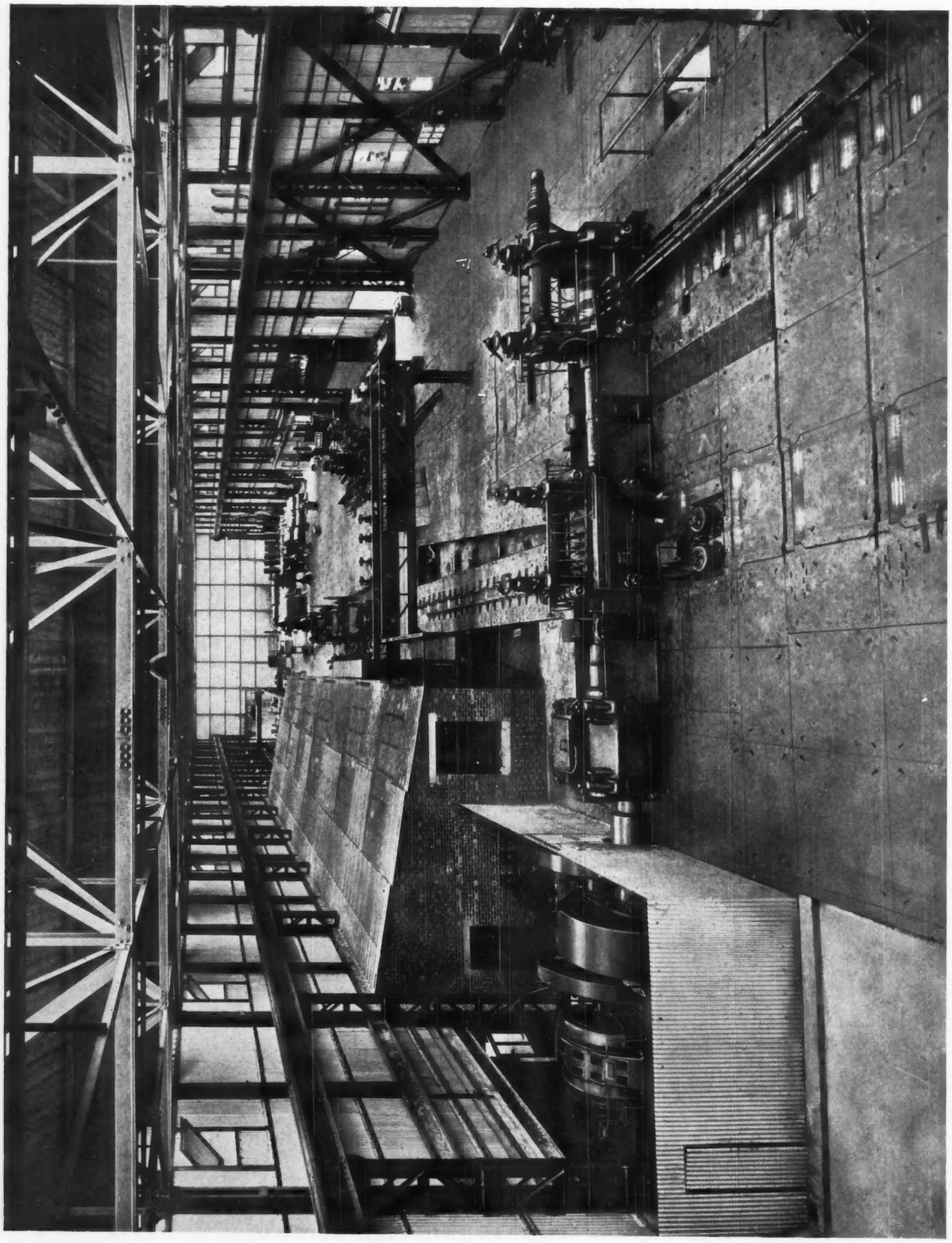

VIEW DOWN THE NEW HOT ROLLED STRIP MILL OF ARTHUR LEE & SONS, LTD.
(*see page 195*)

G.E.C. Journal

VOL. VI. NOVEMBER, 1935. No. 4.

The Electrification of a New Continuous Hot Rolled Strip Mill.

A NEW MILL BUILT AT THE MEADOW HALL WORKS OF ARTHUR LEE & SONS, LTD., OF SHEFFIELD.

By PERCY W. LEE
Chairman of Arthur Lee & Sons, Ltd.
and W. H. WILSON, A.M.I.M.E.
Chief Engineer of Arthur Lee & Sons, Ltd.

HISTORICAL.

THE completion of a new hot rolled strip mill at the Meadow Hall Works of Arthur Lee & Sons, Ltd., Sheffield, is the latest development of a well-known firm which started over seventy years ago as a small wire manufacturing concern in the Porter Valley, trading under the name of James Fairbrother. This small business grew at such a rate that in 1867 the original workshop on the banks of the Porter was discarded and more convenient premises were built in the industrial area of Sheffield. Thus was the "Crown" works

Fig. 1.—Aerial view of the Meadow Hall Works of Arthur Lee & Sons, Ltd.

(the present Head Office of the firm) brought into being.

A change of control occurred in 1874, when the late Mr. Arthur Lee purchased the firm in its entirety from Mr. James Fairbrother, and from 1893 the style and title of the firm became Arthur Lee & Sons, Ltd. The main product of the company at this time was rope wire made almost entirely from crucible steel melted on the premises. As business expanded, however, other branches of the wire trade were catered for, the size of wire manufactured becoming both smaller and larger. Machines for flattening wire were also installed, followed later by cold rolling mills. During this development, the space available at the Crown Works was soon completely occupied and it became necessary to build a new works. A site was acquired at Meadow Hall, a rapidly expanding manufacturing centre 5 miles from Sheffield and 2½ miles from the Crown Works. On this site a modern works was erected for the production of bright drawn wire, bright drawn bars up to 3 ins. diameter, and sections up to 4 ins. wide, and up to 1 in. thick.

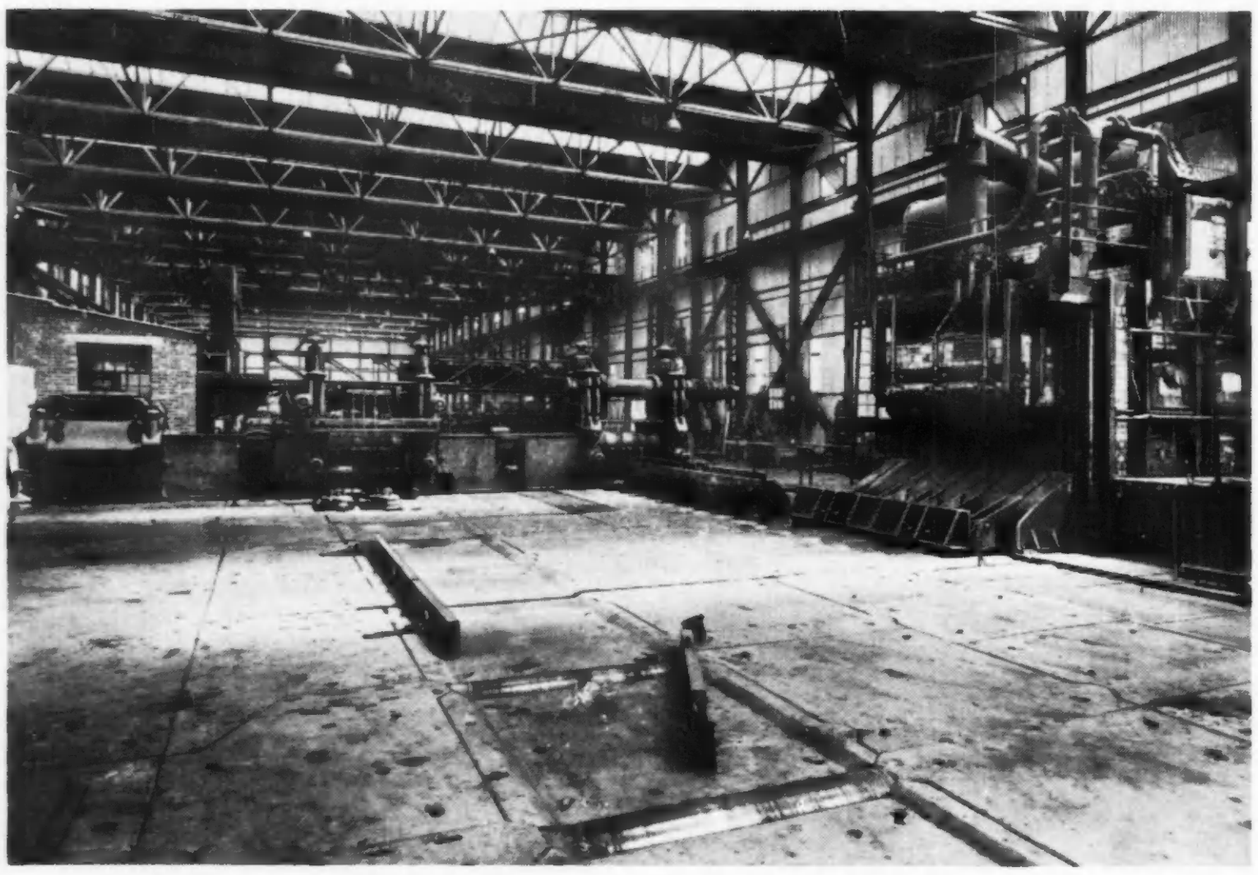

Fig. 2.—Showing the automatic furnace on the right and the main mill in the background.

The latest extension, which is fully described in this article, is an entirely new mill built alongside the existing factory, and enables the Meadow Hall Works to be entirely independent of hot rolled strip supplies from outside sources.

Thus to-day the company possesses a fine series of mills covering over 30 acres and fitted with plant of the very latest design for the manufacture of wire, strip and bars. The comprehensive nature of its manufacturing resources may be gauged from the fact that it produces bright bars and wire of diameters from 3 ins. down to hair thickness, and flat wire and strip from $\frac{1}{64}$ in. up to 30 ins. wide. It is, moreover, an interesting comparison that a whole year's output of the original workshop of James Fairbrother could be obtained from the present works in less than a single day.

NECESSITY FOR THE NEW MILL.

Before describing the actual extensions carried out at the Meadow Hall Works, it will be interesting to consider the circumstances which necessitated the building of the new mill. The first cold rolling mills were put down in 1887, and as trade increased, a hot mill was installed. Since that time the cold roll trade developed to such an extent that the hot mill had become quite incapable of supplying the requirements of the cold mills.

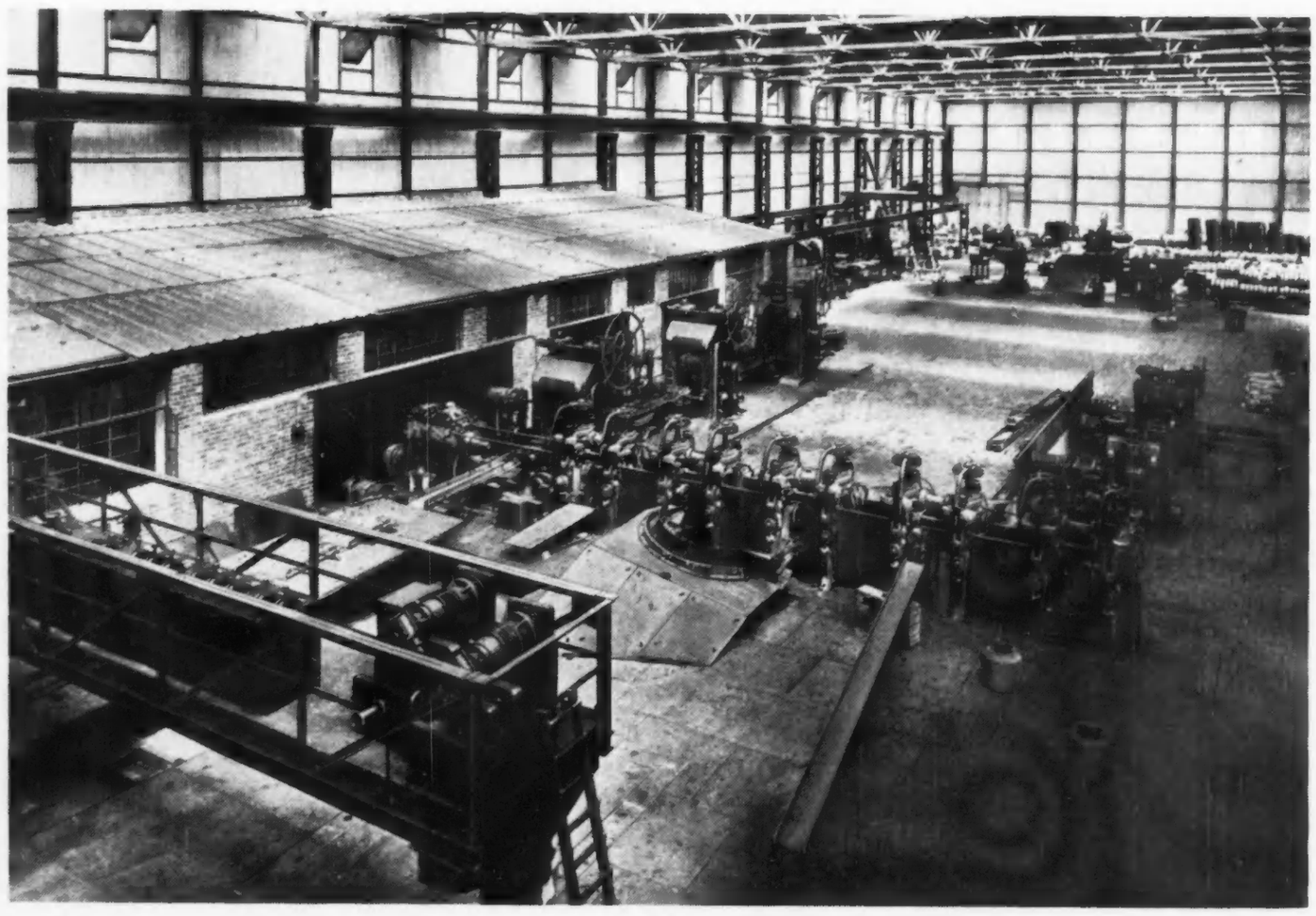

Fig. 3.—General view of the finishing mills.

The policy of the firm has always been towards complete independency of outside sources of supply

other than raw material and it was therefore becoming increasingly evident that either the existing mills would have to be re-organised, or an entirely new mill installed. Two considerations eliminated the former alternative. In the first place, the re-organising of an existing mill would have been extremely expensive and could never have been satisfactory. Secondly, in addition to the increased production of narrow strip, there was a growing demand for wide strip. Cold rolling mills had actually been installed to meet this new demand and it would have been impossible to alter the existing mill in such a way as to undertake this class of work.

It was therefore decided to face the issue boldly and to put down the most up-to-date mill which would meet all requirements.

PLANNING THE NEW MILL.

During recent years, hot rolled strip has been produced abroad with a very much finer finish and with greater accuracy than in this country and as a consequence there has grown up a large demand for hot rolled strip suitable, by reason of its surface condition and its physical properties, for forming up into the finished product without any further heat treatment or finishing process. In planning the new mill, a study was first made of the various types of mills available and the systems on which they worked. The conclusions reached are not without interest. It was found, for instance, that in America the development of hot rolling strip had reached a very advanced stage and that strip up to 6 ft. wide was being produced. The capital cost of such a plant can, however, only be justified by an enormous output.

The Continental firms, on the other hand, had developed a more flexible mill which gave an equally good product with a wide range of sizes up to 18 ins.

After careful consideration of the several requirements, and consultation with various engineering firms, a Continental design was adopted embodying three separate units giving a range of production from 1 in. up to 16 ins. wide and down to the thinnest gauges. At the same time, in view of the demand in the existing mill for black bars for bright drawing, it was determined to arrange the new mill in such a way that at a future date it could readily be adapted for rolling bars.

The scheme finally decided upon was evolved by Schloemann Aktiengesellschaft of Dusseldorf, in conjunction with the company's engineers and technical staff, while practically the whole of the electrical equipment was manufactured and supplied by The General Electric Co., Ltd. Although of German design, a large part of the mill was constructed in this country by Fraser & Chalmers Engineering Works, only a very small portion of highly specialised machinery having been imported.

Fig. 5.—Billet charging platform on top of furnace.

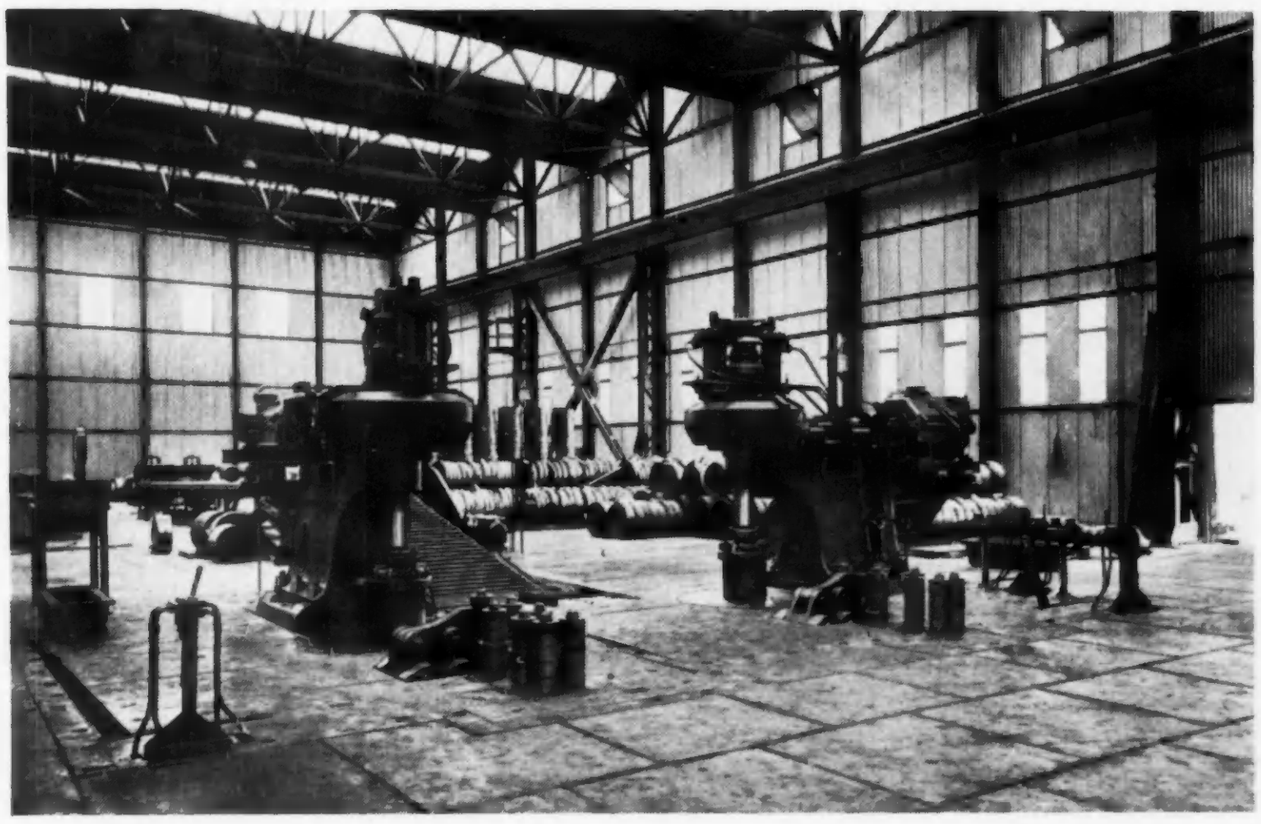

Fig. 4.—Coiling machines. In the background can be seen some of the products of the mill.

THE NEW MILL.

The new mill is built alongside the existing works at Meadow Hall. It will be seen from the aerial view of these works, fig. 1, that the railway runs along both sides of the works. The new mill is to be seen in the foreground occupying the complete width of the site. In the foreground is the billet yard which is 400 ft. long by 65 ft. wide. An overhead electric travelling crane unloads the billets from the railway wagons on the sidings on the right of fig. 1, stacks them and feeds them to the furnace. The same crane also conveys coal

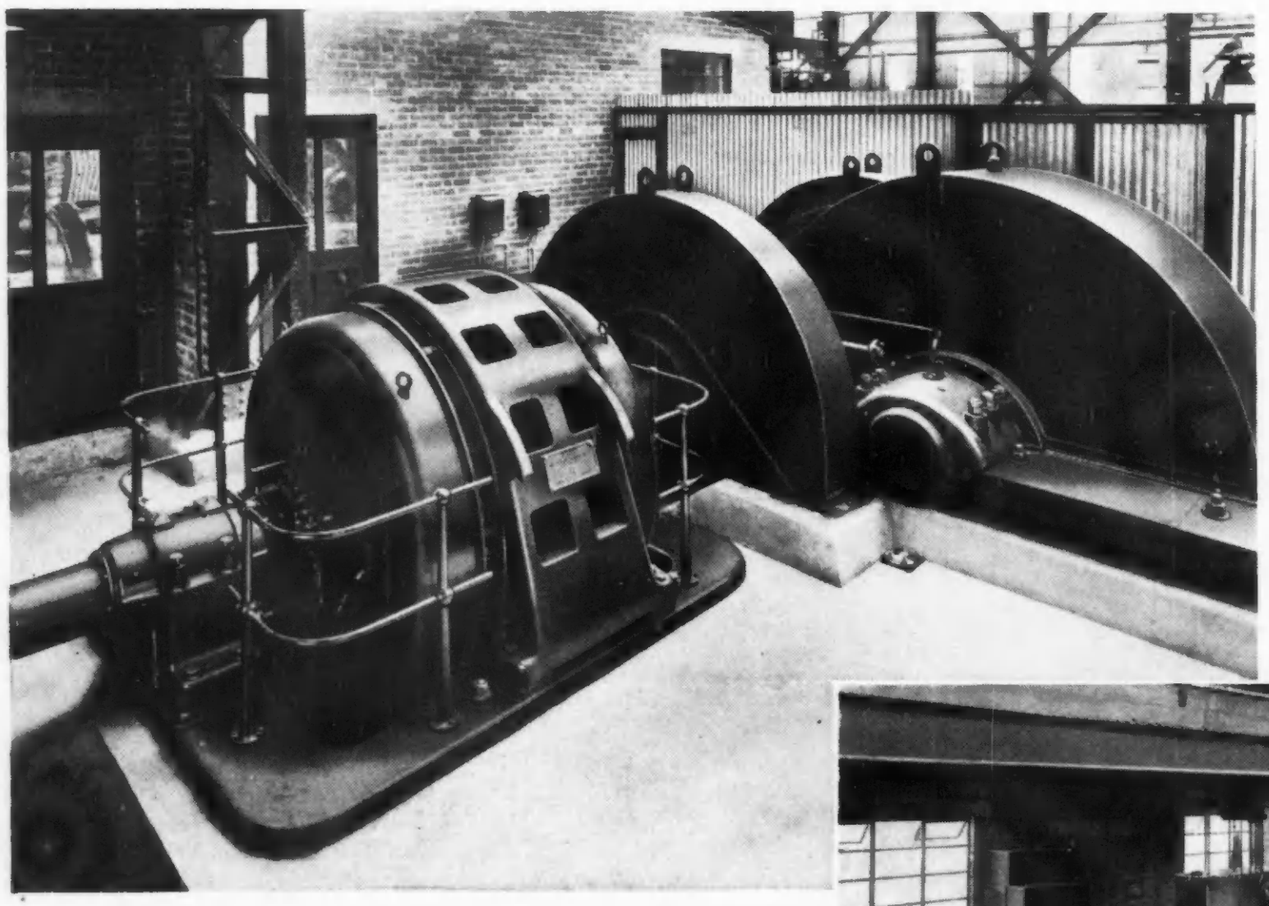

Fig. 6.—1,500 h.p., 6,300 volt, 590 r.p.m. induction motor, driving cogging mill through gearing.

from the wagons into a storage bin. A small auxiliary crane is used to take one or more billets out of each wagon and transport it to the laboratory (situated adjacent to the billet yard) for analysis.

The mill building itself is 400 ft. long by 90 ft. wide and is situated alongside the billet yard (fig. 1). An interior view of the mill taken from the furnace end is shown in the frontispiece, page 194. In the foreground is to be seen the cogging mill with its driving motor on the left, while the furnace which delivers the hot billets to the cogging mill is on the extreme right and is illustrated in fig. 2. Beyond the cogging mill seen in the frontispiece is the platform from which the cogging mill is controlled. The brick building on the left of this platform is the power house which contains the various motors driving the finishing mills. The latter can be seen just behind the control platform. These finishing mills are illustrated in fig. 3. It will be seen that they are divided into three separate units, two units running adjacent to and parallel with the sides of the building and the other running across the mill building. The control platform for these mills is built into the wall of the building facing the power house.

At the far end of the building are situated the coiling machines illustrated in fig. 4.

It is now proposed to deal with the individual sections of the mill in the order in which a billet would pass through them during the process of rolling it into strip.

THE FURNACE.

The billets are taken from the billet yard and delivered by crane direct on to the charging platform of the furnace, fig. 5. This furnace is of the "continuous pusher type," manufactured by Stein & Atkinson, and embodies several special features which have been developed in America for this class of work. The furnace is producer-gas fired, the gas being fed through a series of burners so arranged that the billets are uniformly heated and "soaked" prior to rolling. This is the most important feature of the furnace, for an unevenly heated billet would produce a finished product variable in gauge.

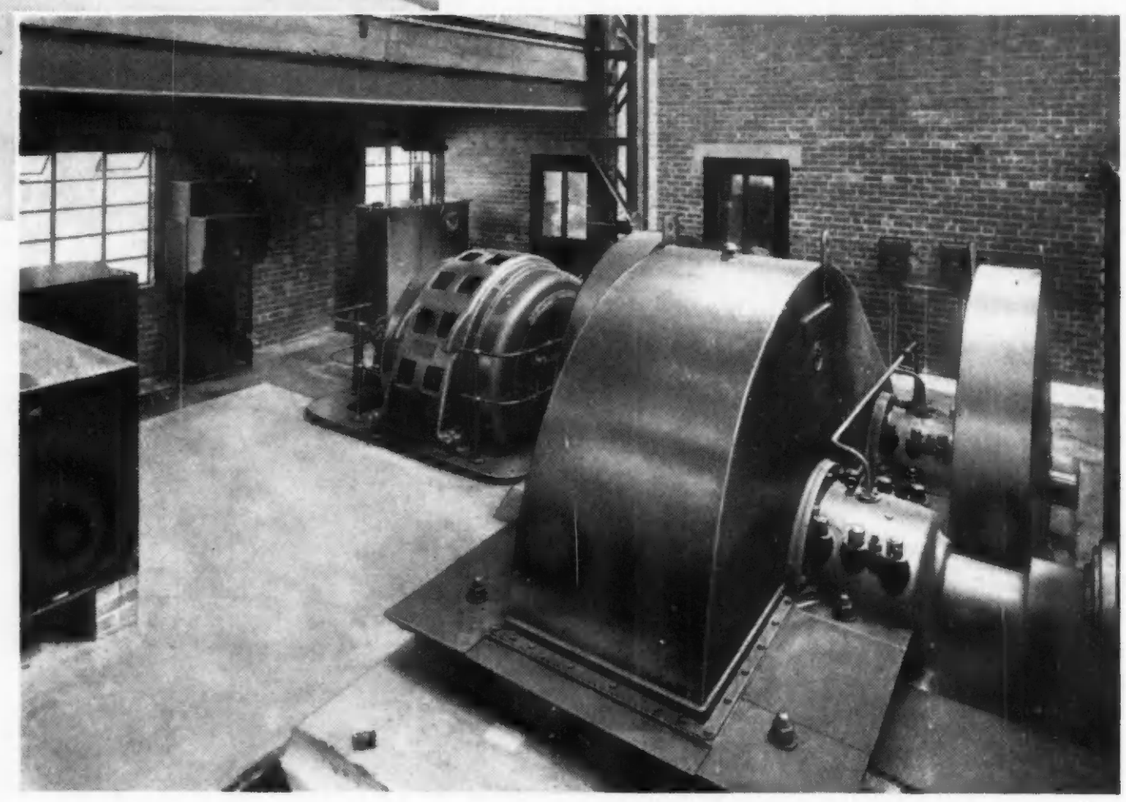

Fig. 7.—Another view of the cogging mill motor, showing the liquid starter in the background and resistance banks on the left.

From the charging platform the billets are fed into the furnace by a pushing machine which is driven by the 20 h.p. motor seen in fig. 5. The hot billets are delivered automatically, one by one, on to the live roller table feeding the first stand in the cogging mill (fig. 2).

COGGING MILL.

The cogging mill consists of two stands each three-high with rolls 21 ins. by 5 ft. 4 ins. and is driven by a 1,500 h.p. 6,300 volt 590 r.p.m. induction motor (figs. 6 and 7) through a single reduction gear to a totally enclosed set of double-helical pinions. The rolls themselves are so drafted that the full range of sizes of billets and slabs can be rolled without having to change the rolls. This is an important feature in view of the size and weight of the rolls and the time it would involve in changing them.

As each billet is delivered from the furnace on to the live roller table, it automatically takes up the correct position for entering the first pass. After the first pass the billet falls on to a live roller table

equipped with lifting gear which lifts the billet and automatically returns it through the second pass. This process is repeated, after which the billet is skidded across to the second stand where it makes the necessary number of passes to prepare it for the finishing mills.

Before the final pass in the cogging mill, the billet, or strip, is rolled through a vertical edging mill (seen just in front of the second stand of the cogging mill). This mill regulates the width of the strip to the exact dimensions required. The mill is separately driven by a 125 h.p. 440 volt 480/960 r.p.m. D.C. motor (fig. 8) through a single reduction gear.

It is notable that all this work is automatically performed under the control of a single man on the control platform (fig. 11).

Before leaving the main mill, it should be mentioned that it possesses all modern auxiliaries, including lifting tables, adjustment of top and bottom rolls, transfer skidders and mechanical repeaters. These are all controlled from the platform associated with this mill, the driving motors being situated below the floor level of the mill. The tilting table motor and the skid motor are rated at 40 h.p. and 25 h.p. respectively and run off the 400 volt 3 phase 50 cycle A.C. supply. All the live roll motors are A.C. squirrel cage machines, some of which are supplied direct from a 400 volt 3 phase 50 cycle system, and the others from a separate variable frequency motor-generator set.

FINISHING MILLS.

As the strip passes through the cogging mill for the last time it is diverted into one of two paths,

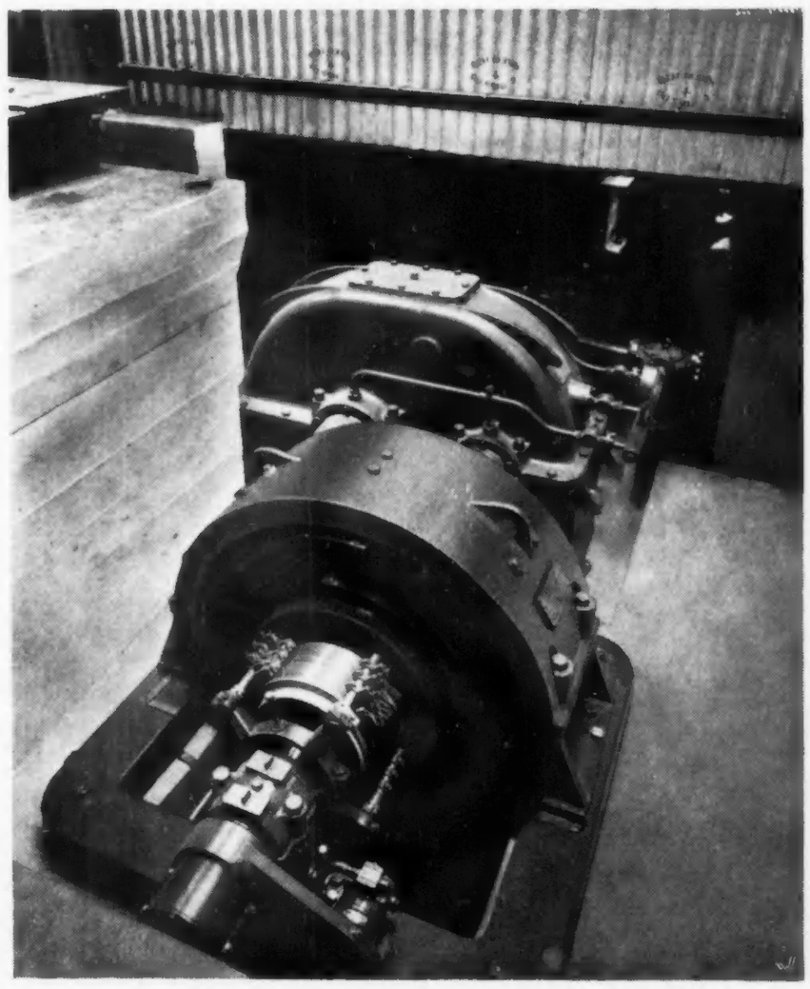

Fig. 8.—D.C. edging mill motor, 125 h.p., 440 volt, 480/960 r.p.m.

depending on the width and gauge required of the final product. When strip of 5 ins. to 16 ins. in width is required it passes straight through No. 1 unit comprising three stands in direct line with the second stand of the cogging mill. When strip of

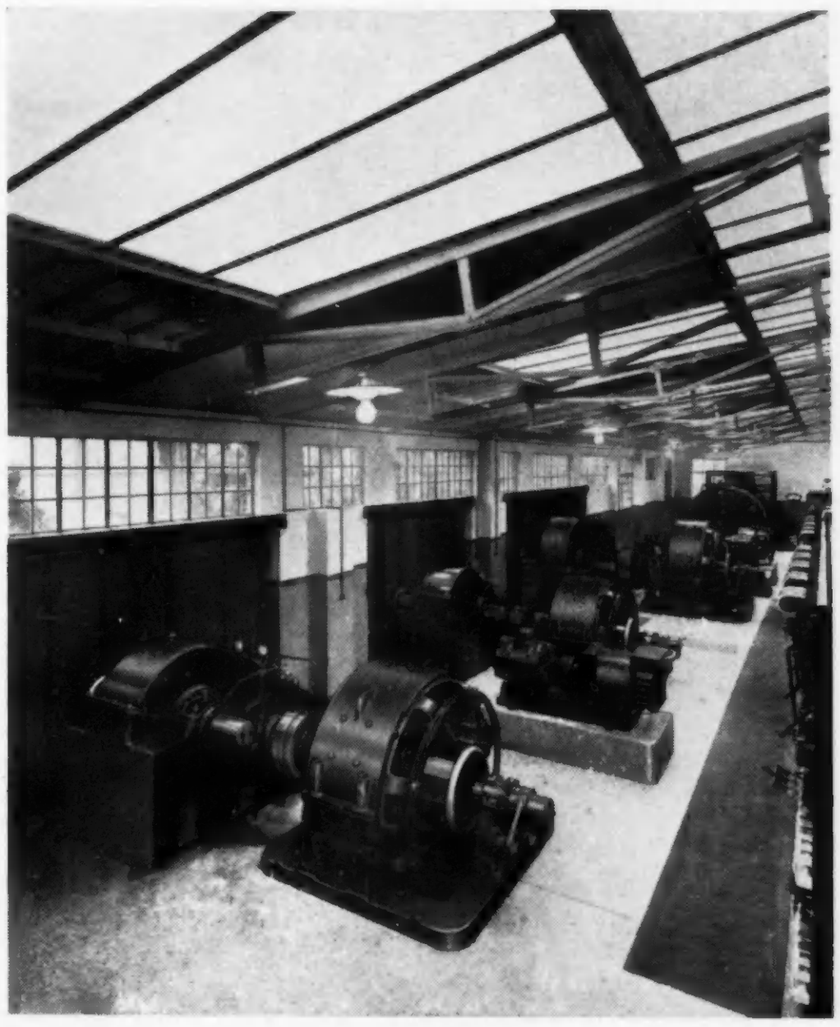

Fig. 9.—View in power house, showing the 1,000 h.p. and two 650 h.p. D.C. motors driving the finishing mills.

less than 5 ins. width is required it is taken through No. 2 unit, known as the "intermediate" or "cross-country" mill, which comprises five stands running in line across the building. Thence the strip is passed through two small finishing mills comprising No. 3 unit, the first stand of which is placed in tandem with the last stand of No. 2 unit.

These three units are described in greater detail below.

No. 1 Unit.

The three stands of No. 1 unit alongside the power house are placed in a line to ensure the continuous movement of the strip as it leaves the cogging mill. Each stand contains three rolls mounted on roller bearings. The middle work roll of each stand is comparatively small in diameter and is supported on the top by a large backing-up roll which is driven by a separate variable speed A.C. motor. The bottom work roll of the first stand is driven by a 1,000 h.p. variable speed D.C. motor through a reduction gear, while the bottom work roll on each of the two successive stands is driven by a 650 h.p. variable speed D.C. motor through reduction gear. Loop lifters are provided between the mills to take up any slack which may develop in the strip as it passes from one mill to the next. These loop lifters are

operated by special A.C. torque motors. Each unit is also equipped with rapid roll adjusting and roll changing devices, and automatic scrapers.

The motors driving these mills are illustrated in fig. 9. The two motors in the foreground of the illustration are each of 650 h.p. while the 1,000 h.p. motor driving the first of the three mills can be seen between the further 650 h.p. motor and a rotary converter which supplies the three motors with D.C. The reduction gears of the 1,000 h.p. motor are provided with two output shafts one of which drives the first stand of No. 1 unit, while the other drives all the stands of No. 2 unit. Each of the reduction gears of the 650 h.p. motors is also fitted with two output shafts, one of which drives a stand of No. 1 unit and the other a stand of No. 3 unit.

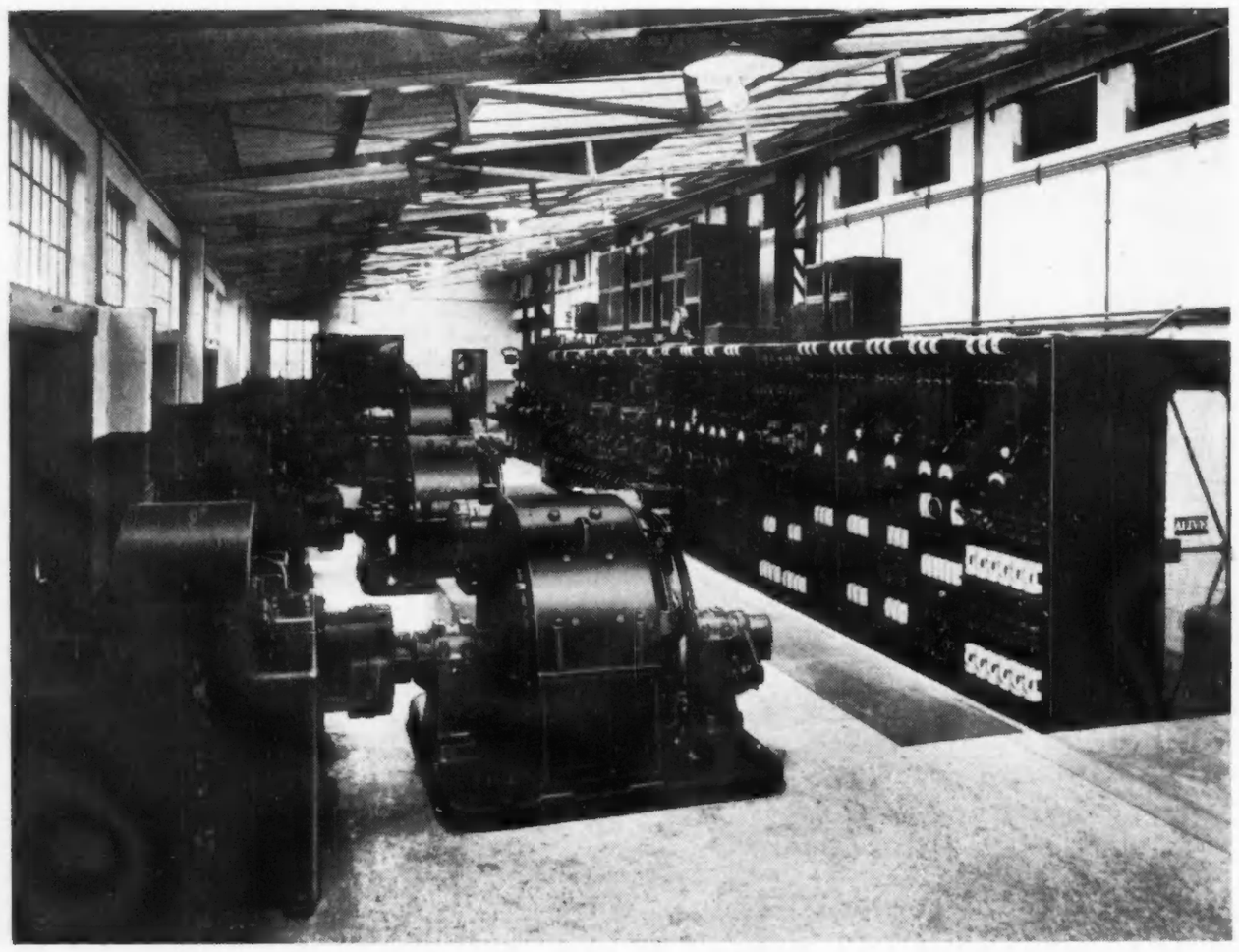

Fig. 10.—Another view in the power house, showing the main control board and the finishing mill motors.

The driving shafts of these mills extend from the motors across the mill under the floor.

No. 2 Unit.

The intermediate mill is provided with three-high double helical pinions which drive a train of five stands each comprising three-high rolls, 13 ins. in diameter. The stands are provided with automatic repeaters, interchangeable roll frames, bottom roll adjustments and a quick roll-changing device. It is noteworthy that the roll frames of the intermediate mill can be removed as one unit and replaced by another in the course of a few minutes. This feature will enable bar rolling to be carried out in the future.

The strip as it comes from the cogging mill, 5 ins. or less in width, is handled by a man who shears the end before placing it in the first pair of rolls of the intermediate mill. This is the first time that the material has been man-handled since its arrival at the works.

No. 3 Unit.

No. 3 unit consists of two continuous type stands similar to those of No. 1 unit, but of smaller dimensions. The strip automatically passes through the five stands of the intermediate mill and then through the two stands of No. 3 unit. In this way, the strip can be reduced down to 21 gauge.

COILING MACHINES.

Two coiling machines are installed (fig. 4) both being of the vertical type. Each coiling machine is driven by a 25 h.p. 440 volt D.C. motor running at 400 800 r.p.m. As the strip leaves the last stand of the finishing machines it is inspected for width and gauge and automatic means are provided for informing the roller immediately of any discrepancy that may occur. The strip is then guided through a series of vertical rollers which "kill" the natural kinking of the strip as it passes over the floor. After coiling, the strip is diverted on to a conveyor which deposits it on carriages. It is then weighed, marked, bundled and stacked ready for despatch.

In cases where strip is required in straight lengths, it is run straight out from the finishing mill on to a cooling table from which it is fed into an automatic machine for cutting it into lengths and bundling. Arrangements are also made for pickling and oiling, if required.

ELECTRICAL EQUIPMENT.

The electrical equipment of the mill is of a particularly comprehensive nature, the motors employed aggregating over 4,000 h.p. in capacity. Electricity is relied upon not only as a source of power, however, but also for the control of the extremely delicate operations necessary in the automatic working of the various units.

Power is taken from the supply mains of Rotherham Corporation at 6,600 volts 3 phase 50 cycles. Part of this supply is transformed down to 400 volts by a 500 kVA transformer to provide a low tension A.C. supply for the various auxiliaries, while part is converted into D.C. at 440 volts by a 2,000 kW rotary converter. This feeds the three finishing mill motors and the edging mill motor. A further portion of the high tension incoming supply is taken direct to the 1,500 h.p. cogging mill motor.

Although reference has already been made to these motors, it will be of interest to give certain further details.

Cogging Mill Motor.

The main mill motor is of the standard induction type and is rated at 1,500 h.p., 6,300 volts, 3 phase, 50 cycles and runs at a speed of 590 r.p.m. With it are associated a liquid starter and two banks of air-cooled resistances of the cast grid type. One of these banks functions as a slip resistance to enable the flywheel to deliver its energy on peak load, while the other acts as a braking resistance and is intended for use only when the motor has to be stopped in emergency. The design and construction of the machine are such that the heavy overloads encountered in rolling mill practice can be handled with safety.

Edging and Finishing Mill Motors.

The D.C. motors driving the edging and finishing mills are rated as follows :—

125 h.p., 440 volt, 480/960 r.p.m. motor driving edging mill.

1,000 h.p., 440 volt, 360/720 r.p.m. motor driving first stand of No. 1 unit, or all 5 stands of No. 2 unit.

650 h.p., 440 volt, 280/560 r.p.m. motor driving second stand of No. 1 unit, or first stand of No. 3 unit.

650 h.p., 440 volt, 280/560 r.p.m. motor driving third stand of No. 1 unit, or second stand of No. 3 unit.

These motors are of the open type and are shunt wound, fitted with light stabilising windings, compensating and interpole windings. The full rated output of each machine is given at any speed over its range, while the inherent speed regulation between no load and full load does not exceed 3 per cent. A rheostat in the shunt field is employed to control the range of speed.

Excitation of the three motors is obtained from a separate 60 kW motor generator set, the motor of

Fig. 11.—Control platform "A," from which all operations on the cogging mill are controlled.

Fig. 12.—Control platform "B," controlling finishing mill motors.

which runs off the 400 volt A.C. supply. A second motor-generator set of 40 kW capacity supplies power for the travelling crane and the roll turning

lathes, while a third motor generator set of 30 kW capacity supplies A.C. at variable frequency for the variable speed motors driving the top rolls of the finishing mills.

The three D.C. finishing mill motors, the three motor-generator sets, the rotary converter, the a flat back switchboard, measuring 51 ft. in length, is installed in the power house and with it are associated the control platforms previously mentioned. It will be remembered that the cogging and edging mills are controlled from a platform immediately behind the cogging mill. This platform is known

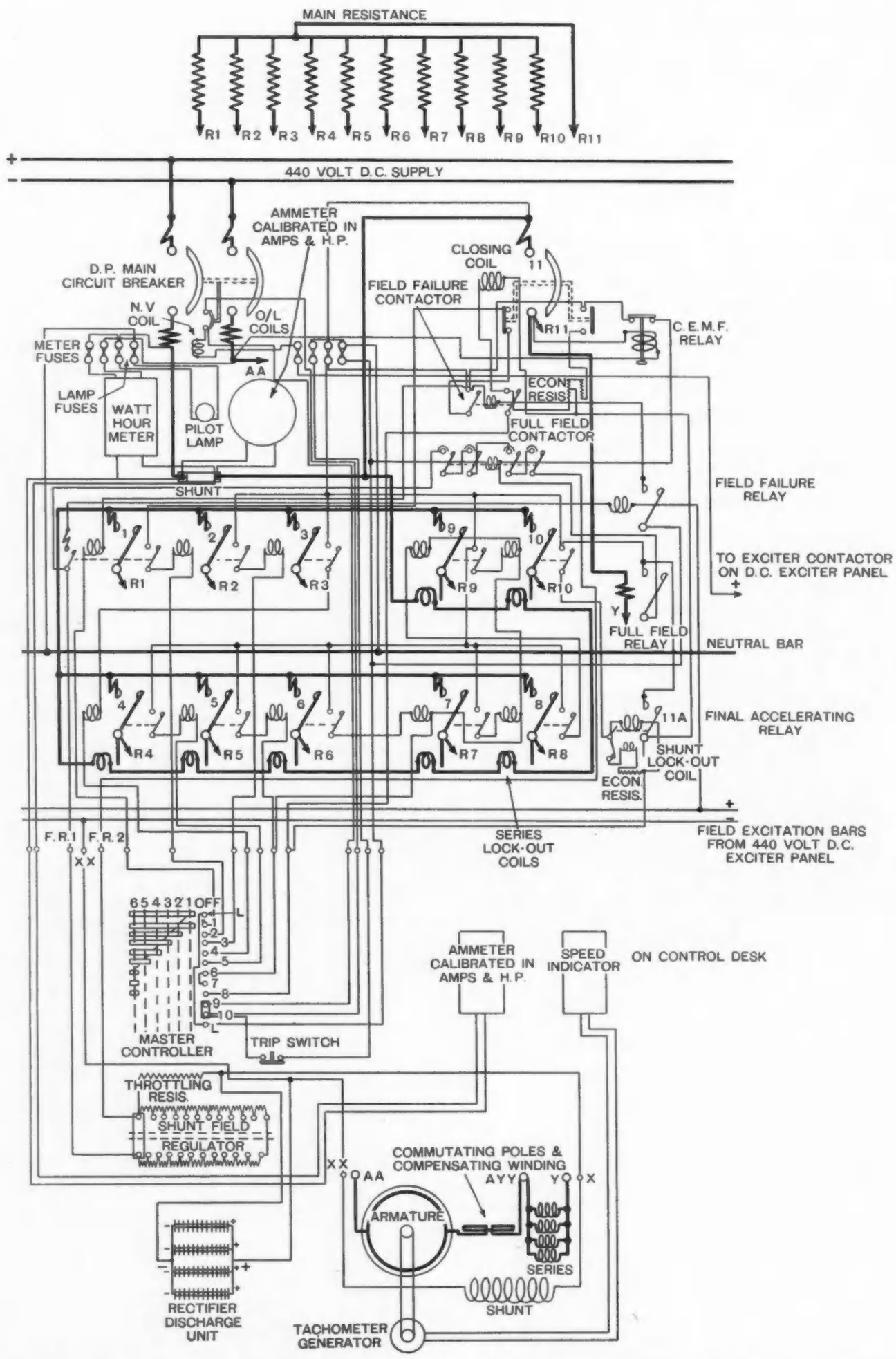

Fig. 13.—Circuit diagram, showing control of the 1,000 h.p. finishing mill motor. Similar control is applied to the 650 h.p. motors.

transformers and the main control board are situated in the power house, views of which are given in figs. 9 and 10.

MOTOR CONTROL EQUIPMENT.

For the control of the various rolling mill motors as control platform "A" (fig. 11) while the control platform associated with the finishing mill motors is known as control platform "B" (fig. 12). The control desks on these platforms carry lever-operated master controllers, speed indicators, meters, adjusting regulators and push buttons so that the operator

not only has control of the equipment but is also fully informed as to the behaviour of his apparatus.

The desk on platform "A" controls :—(1) Tilting table rollers, (2) Tilting table, (3) Shifting device on tilting table, (4) Work table rolls, (5) Work table skid, (6) Roller table, No. 2 stand, (7) Edging mill motor, (8) Cogging mill motor and (9) Screw-down gear.

Platform "B" controls :—(1) Finishing mill roller table, (2) Loop lifter motors, (3) 1,000 h.p. motor and (4) the two 650 h.p. motors.

The switchgear through which the control equipment on platforms "A" and "B" excercise their functions is mounted on the main control board in the power house. The first three panels of this board (*i.e.* those at the far end in fig. 10) control the rotary converter, while the two adjacent panels carry starting gear for the 1,000 h.p. D.C. motor controlled from platform "B". This gear comprises a ten-step contactor starter, each contactor paralleling resistance steps. The first three steps are directly under the control of the master controller and are designed to give one-third, two-thirds and full load torque at standstill. The succeeding seven steps are also actuated from the controller but in addition have current limiting devices. The final step is furnished by an electrically operated line contact circuit breaker closing under hand and timing control. A diagram of connections for the 1,000 h.p. motor is given in fig. 13.

The starter is fully protected by a counter-e.m.f. relay (which prevents re-starting with a high armature voltage) field failure and full field relays, and double pole overload relays. The field of the motor itself is also protected by a rectifier in place of the usual discharge resistance, an arrangement which has effected a considerable saving in space and power loss.

The main resistances are mounted above the switchboard, while a recording wattmeter, indicating ammeter and pilot lamp completes the equipment. Two similar sets of starting gear occupy the next four panels of the switchboard and control the two 650 h.p. D.C. motors.

To the right of the 650 h.p. panels is the starting equipment of the edging mill motor. The lower horse power of this motor allows the use of only five starting steps. This machine is also provided with a fine speed adjusting series diverter at the control desk.

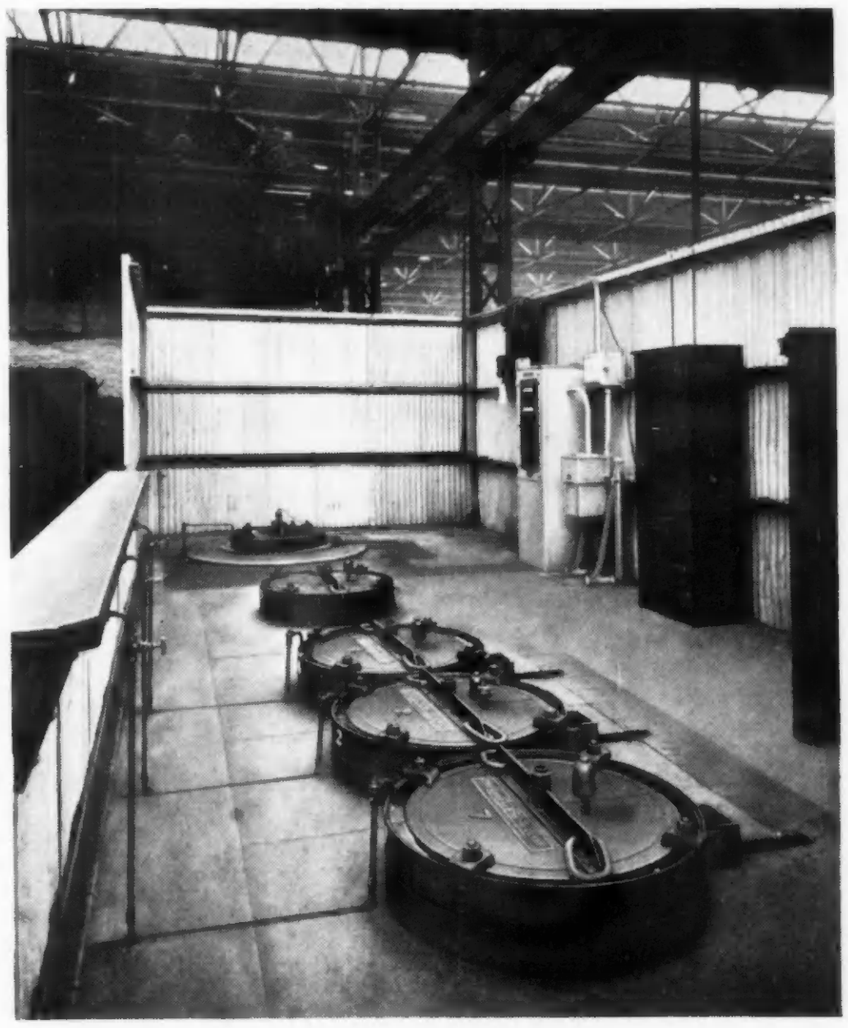

Fig. 14.—Electric furnace equipment for the bright annealing of steel strip.

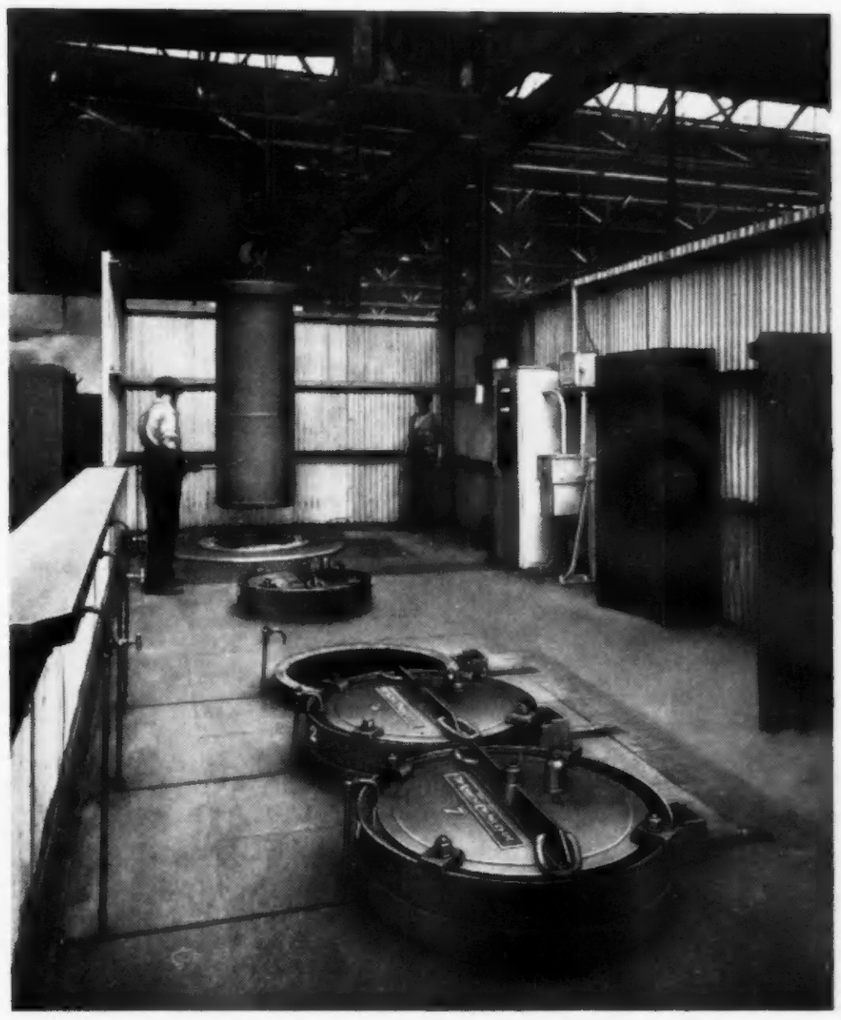

Fig. 15.—Showing a charge being lowered into the furnace.

The next two panels carry switchgear for the top roll drives of the finishing mills. These drives are carried out by means of squirrel cage motors deriving their power from a variable frequency alternator driven by a D.C. motor. The control panels of the motor are therefore equipped with a starter, speed and voltage regulators, frequency meter, voltmeter and alternator circuit breaker.

On the panel controlling the excitation motor generator set an automatic auto-transformer starter is mounted and is actuated from push buttons on the panel. The excitation supply is controlled by a panel of the standard type. Field protective

contactors are arranged to cut out all D.C. machines in the event of excitation failure.

The 25 h.p. coiling machine motors are each controlled by four push buttons mounted close to the coiling machines, the control equipment being mounted on a panel of the main board. This equipment consists of a four-step lock-out starter for each motor, actuated by two of the push buttons marked "Start" and "Stop," while a motor operated field regulator is controlled by the remaining two buttons marked "Fast" and "Slow."

The five panels at the end of the main switchboard, control incoming and outgoing low tension A.C. supplies and the 40 kW motor generator set.

In addition to the equipment described above, each control platform is provided with an auxiliary panel comprising sheet steel cubicles containing reversing direct-to-line starters, fuses and isolating switches. This equipment is for the operation of auxiliaries such as the live roll motors, tilting table motor, skid motors, loop lifters, top rolls, etc. In the case of the reversing direct-to-line starters on platform "A" it should be mentioned that they are of special design and are capable of performing the exceptionally heavy duty involved in operating 600 times an hour.

BRIGHT ANNEALING FURNACE.

For the purpose of producing bright annealed cold rolled steel strip an electric furnace plant (figs. 14 and 15) is installed in another part of the factory and is of particular interest in that it was the first installation of its kind in Great Britain for the bright annealing of steel. Since its installation, many other similar equipments have been supplied to steelworks for this class of work. It comprises a G.E.C. vertical cylindrical "Grunewald" electric furnace with automatic temperature control gear and eight "Grunewald" bright annealing pots.

The furnace has an electrical rating of 88 kW and has several interesting features which are peculiar to the "Grunewald" process. While it is not proposed to describe this process in detail as it has already been dealt with elsewhere*, it should be pointed out that the most important of its features arises from the fact that no artificial gas atmosphere is required. Further, the charge is suspended from the underside of the pot cover and is not supported by the pot envelope which is consequently made of thin heat-resisting alloy.

Each pot is sealed by a rubber ring which is cooled from the outside by a trickle of water.

The automatic temperature control gear enables the furnace automatically to maintain any desired temperature within narrow limits. The whole of this equipment is carried on a polished panel, and comprises a Cambridge direct deflectional type controller working from a thermo-couple situated on the furnace, together with pilot lamps and switch and fuses for the control circuit.

Incorporated in the controller is the necessary mechanism for tilting a small mercury switch which makes and breaks the contactor coil circuit, a red pointer being provided for setting purposes. A time switch is included which switches the furnace on or off automatically at any pre-determined time. An additional Cambridge indicating pyrometer is provided on the control panel; this works from a thermo-couple situated in the middle of the charge in the pot, thus indicating the temperature of the charge.

The switchgear consists of a pedestal mounting oil switch and an air break contactor, the latter being mounted in the steel cubicle previously mentioned. The contactor, in this particular instance, cuts in and out a portion of the load just before the set temperature is reached—thus avoiding any overshooting of the set temperature.

The determining factor in the installation of this furnace was the quality of the work produced, and in this respect it has fully justified itself. Moreover, it has proved an economic proposition, considered on a combined time and fuel basis. The pot takes a charge of approximately 30 cwts., the time of treatment being 6 hours as against the 24 hours required with the standard method.

* See G.E.C. Journal, Vol. III., No. 2. p. 87.

The Design of Precision Commercial Photoelectric Photometers.

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Research Laboratories of The General Electric Co., Ltd., Wembley, England.

In the G.E.C. Journal, Vol. III, No. 3, August 1932 there was described an early type of photometer in which photocells were applied to the measurement of lamps under commercial conditions. Since then there have been considerable advances, and in this article the authors give an account of some of the recent developments in the design of photoelectric photometers.

Photometers have been constructed capable of precision measurement at commercial speeds of tungsten filament lamps from 10 to 60,000 lumens (i.e., lamps rated at 2 to 3,000 watts); also photometers for the measurement of the recently developed discharge lamps.

1. EARLY PHOTOMETERS.

THE preliminary stages in the development of photoelectric photometers at the G.E.C. Research Laboratories have already been fully described, as well as their subsequent application to commercial routine photometry[1].

Design.

The first types used were integrating photometers employing an emission, or Elster Geitel photocell in conjunction with a D.C. valve bridge amplifier. In this arrangement, with the photocell dark, the balancing of the amplifier bridge is indicated by the null reading of a galvanometer. Light falling on the photocell throws the bridge out of balance, but by applying additional grid bias from a calibrated potentiometer, balance can be restored. The voltage applied by the potentiometer is then proportional to the photoelectric current and therefore to the light. In these photometers the lamps are operated inside spherical photometric integrators. Light reaches the photocell, which is housed in a subsidiary integrator, *via* an aperture in the main integrator, screened from the direct light from the lamp. A suitable filter over this aperture enables adjustment to be made for the departure of the spectral response of the photocell from that of the "average eye." A micrometer shutter, adjustable over the aperture in a direction at right angles to that of the filter adjustment, enables the overall sensitivity of the photometer to be altered without disturbing the ratio of filtered to unfiltered light, and therefore the "colour sensitivity" of the cell and filter arrangement.

Calibration.

Photometers of this type are calibrated by reference to standard lamps which cover the range of lumens and colour temperature of the lamps which the photometer is designed to handle. The position of the colour filter is adjusted by trial and error until a position is found in which the potentiometer readings are proportional to the lumens of the standard lamps. This ensures that inaccuracies will not arise due to the different lamp operating temperatures, and frequent readjustment is not necessary.

The photometer is calibrated to read directly in lumens by setting the potentiometer at the standardised lumen value (or a convenient multiple) of each of the standard lamps in turn, and adjusting the micrometer shutter until the galvanometer is balanced. Differences between shutter settings should not exceed an amount equivalent to 1 per cent in lumens. By setting the shutter to the mean of these values a reliable direct reading calibration is obtained over the range of lumen values covered by the standard lamps.

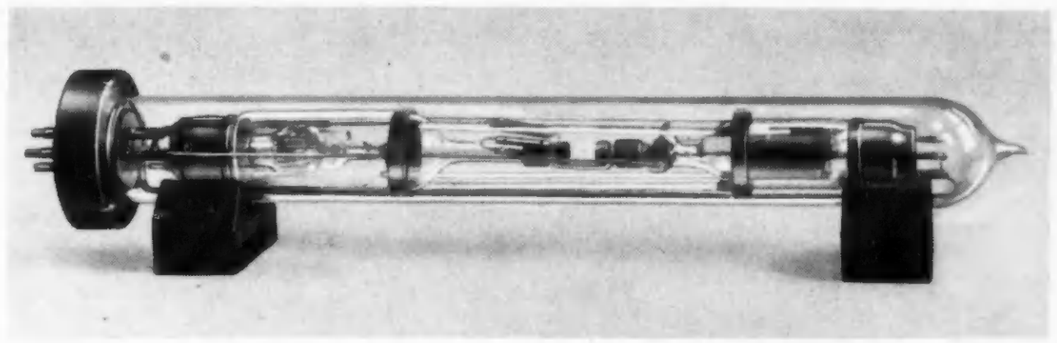

Fig. 1.—Experimental valve photocell unit.

Operation.

Having calibrated the photometer, the following procedure is adopted for measuring the lamps.

First, with the photocell dark and the potentiometer set to zero the D.C. amplifier bridge is balanced by means of the adjustable resistance in the

anode circuit. Actually a zero checking key is provided which performs the equivalent operation of setting the potentiometer to zero without the necessity of moving the dials. The lamp to be measured is then switched on, the voltage across its terminals adjusted to the required value, and the potentiometer adjusted until the galvanometer is balanced. The potentiometer then indicates directly the lumens of the lamp.

Accuracy and reliability.

Statistical analysis[2] of the results of check measurements made in the Standardising Laboratory of the G.E.C. Research Laboratories on lamps taken daily at random, during the years 1927 to 1930, from batches of lamps measured in the ordinary course of commercial routine on visual and photoelectric photometers, showed clearly that the accuracy obtained at commercial speeds, using photoelectric photometers of this type, is greatly superior to that possible by visual methods.

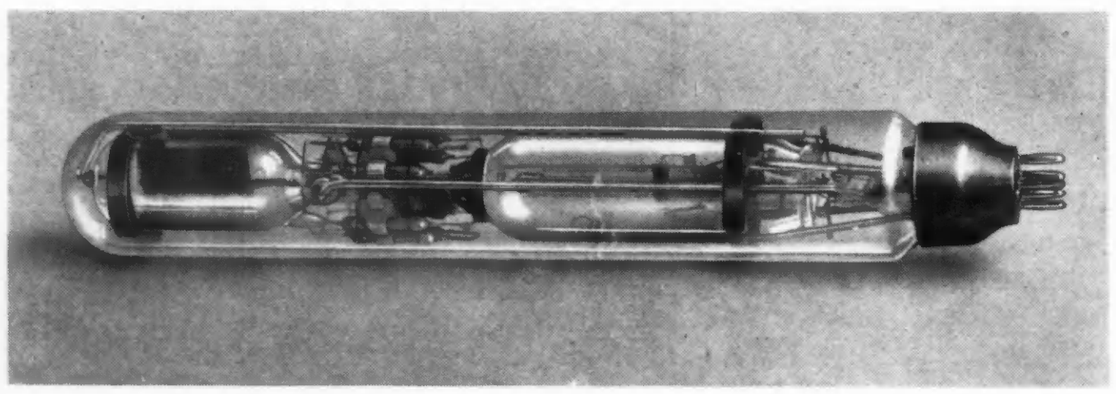

Fig. 2.—Valve photocell unit in its present form.

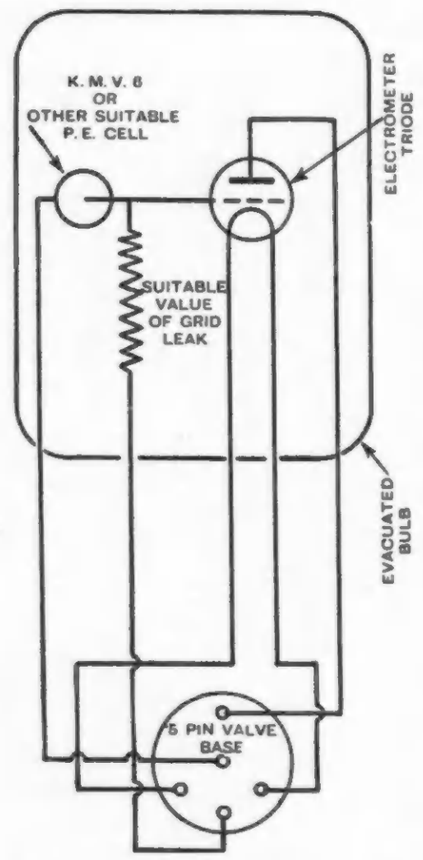

Fig. 3.—Circuit diagram of the normal valve photocell unit.

However, although improved accuracy was shown to have resulted from the introduction of the new type of photometers, the design of the apparatus used up to 1933 involved the use of amplifiers employing carefully selected valves operating at anode voltages up to 160 volts. In order to obtain the stability necessary for accurate and continuous working, H.T. accumulators, which required recharging weekly, were used in preference to dry batteries. The L.T. accumulators required similar weekly charging, and this, together with insulation troubles which arose due to surface leakage, particularly in the grid circuit, called for a considerable amount of maintenance. It is not surprising, therefore, that from time to time these early photometers developed faults which required the attention of staff of the type normally only available in a laboratory.

This difficulty tended to retard the general adoption of these photometers in place of visual photometers for lamp rating purposes in the factory.

2. IMPROVEMENTS IN AMPLIFIERS.

Experiments demonstrated that an improvement could be effected by the use of the type of valve known as the electrometer triode[3]. These valves have very high grid insulation and require an anode voltage of only about 10 volts. This combination of extreme stability and low anode voltage promised a means of overcoming the difficulties due to amplifier instability and of reducing the maintenance costs.

Owing to the low mutual conductance of the electrometer triode it became necessary to use grid leak resistances of higher values, in order to obtain the degree of amplification which had been possible when using the receiver class of valves.

The first attempts to use the electrometer triode in a photoelectric photometer were not very successful, due to variations in the insulation of the grid circuit and also instability arising from external high frequency electrical disturbances. The latter trouble appeared to be due to the inadequate screening of the amplifier.

Valve Photocell Unit.

In an attempt to overcome the difficulties referred to in the previous section, a new form of amplifier was evolved, in which the photocell was mounted directly on the top of an Osram electrometer triode, and these components, together with the grid leak, were enclosed in an evacuated bulb. In this manner the grid lead was kept extremely short, and surface leakage troubles were overcome by virtue of the grid circuit operating in vacuo. An early experimental construction of valve photocell unit incorporating these features is shown in fig. 1.*

The tubular bulb containing the photocell, grid resistance and valve was sealed, with vacuum wax, into an annular groove in an ebonite base, through which passed the electrical connections. Tests showed that with this arrangement, grid insulation could be maintained constant, with grid leak resistances up to 10^{11} ohms. A "unit" was subsequently developed[4] which was similar in principle to the experimental model, but of more robust construction. This construction, together with the circuit arrangements inside the bulb, are illustrated in figs. 2 and 3 respectively. The components are mounted on a glass pinch, sealed into the bulb as in lamp and valve construction, and the connections are brought out through a 5-pin valve base. The results

* The second example of this early type of amplifier, built by the Research Laboratories, was installed in the Osram G.E.C. Lamp Works for high wattage lamps in 1930, and is still in regular use.

of tests on this unit indicated that its incorporation in photoelectric photometers would result in improved performance, with the added advantages of compactness and a considerable reduction in the number and size of batteries required. This economy in batteries automatically eliminates the worst of the maintenance problems, and, because of the greater compactness, efficient screening of the component parts can be more simply achieved.

It has since been found that these valve photocell units have a wide field of application. Grid leak resistances up to 10^{11} ohms have been used without impairing the stability of the amplifier. In precision photometry KMV6 photocells (vacuum) having a sensitivity of 1 to 2 micro amps. per lumen are used, since their response is both linear and stable. Using a high sensitivity galvanometer with an amplifier of this type, fitted with a 10^{11} ohm grid leak resistance, it is possible to measure 5×10^{-7} lumens to a precision of from 1 to 2 per cent.

Another form of valve photocell unit has been developed, which has been found useful in cases where it is required to make differential measurements, such as the comparison of the intensity of two beams of light, etc. It is shown in fig. 4, while the familiar circuit in which such a unit can be used is shown in fig. 5. This circuit was used in earlier photoelectric photometers designed for measuring colour temperature[5].

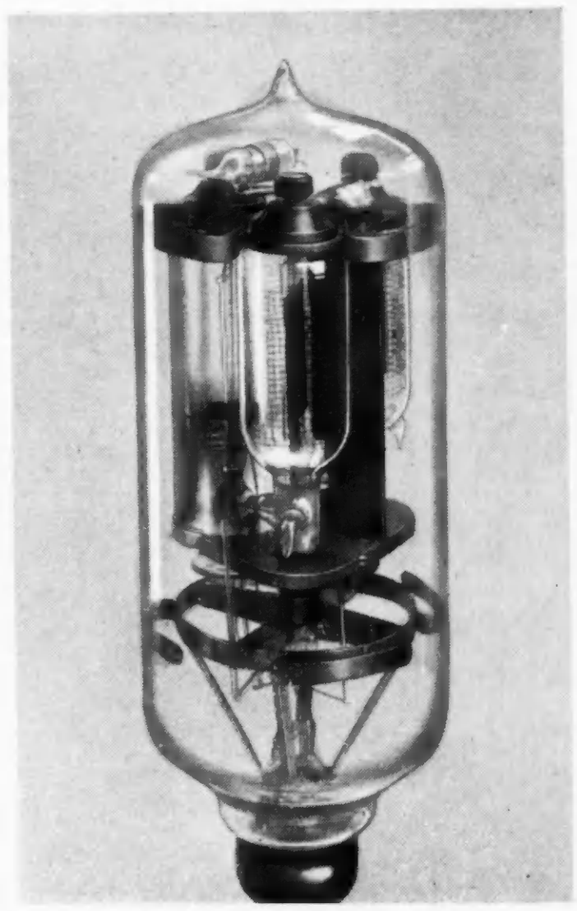

Fig. 4.—Valve photocell unit incorporating two photocells.

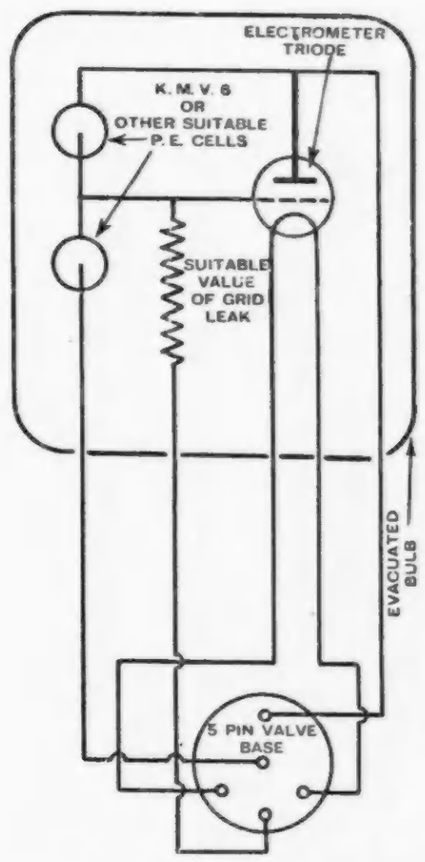

Fig. 5.—Circuit diagram of the double cell unit.

3. DIRECT READING "LUMEN-PER-WATT" PHOTOMETER.

The satisfactory results obtained with this valve photocell unit stimulated interest in the lumen-per-watt type of photometer, the preliminary development of which was begun in 1930[6]. This type of instrument was then only in the experimental stage, and had not been used in the factory because of the instability associated with amplifiers utilizing receiving valves.

The principle of operation of this type of photometer has already been described,[7] but for the sake of completeness is briefly outlined below.

In this photometer, advantage is taken of the fact that where lamps are manufactured under closely controlled conditions, the variation in lumen and more particularly watt rating of individual lamps of the same nominal rating is comparatively small. Nevertheless, it is desirable to determine the magnitude of the spread in efficiency at rated volts for sample lamps, so that the necessary control of the manufacturing processes can be maintained.

For small changes in lumens and watts from the same nominal value, an approximation to the lumens per watt can be obtained by a subtractive method. For example, the lumens per watt of a badly rated lamp having 121 per cent nominal lumens and 104 per cent nominal watts will have an efficiency of $\frac{1.21}{1.04} = 1.163$ or 116.3 per cent lumens per watt, *i.e.*, 16.3 per cent above the nominal lumens per watt.

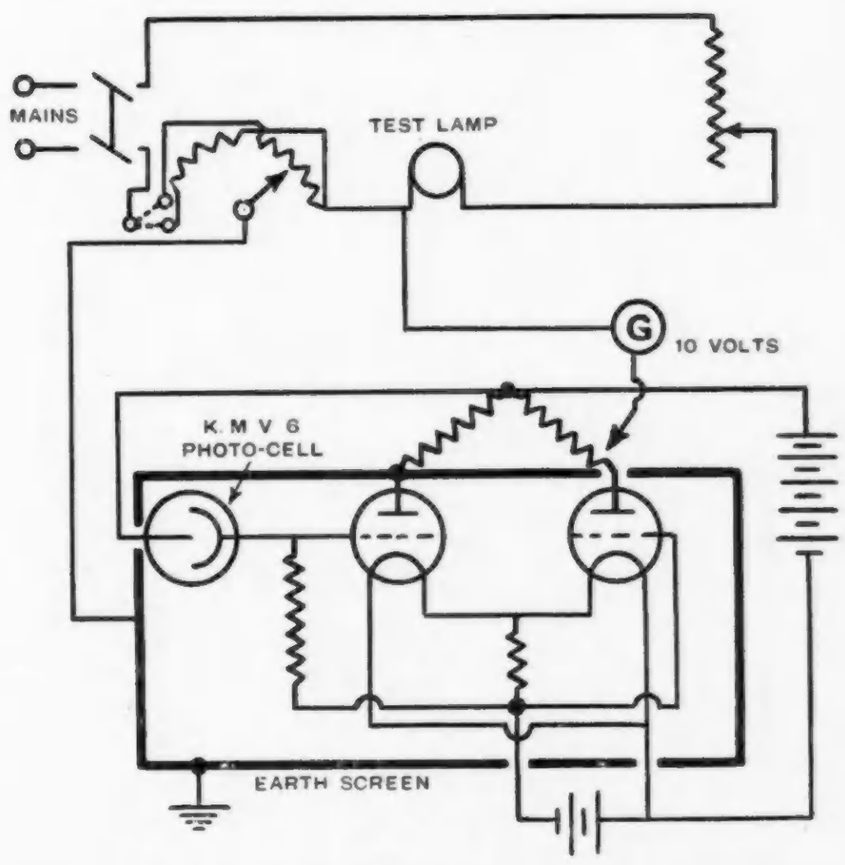

Fig. 6.—Circuit diagram of experimental lumen-per-watt photometer.

Alternatively 121% − 104% = +17%, or 17% above nominal lumens per watt. The error in this particular approximation amounts only to 0.7 per cent in lumens per watt. As the maximum deviations from normal can be kept considerably less than that quoted in the example, it will be appreciated that for measurements of this type the errors due to this approximation can be neglected.

In fig. 6 is shown the original circuit used in order to obtain a deflection proportional to the difference between a voltage component proportional to the lumens of the lamp, and another component proportional to the watts of the lamp.

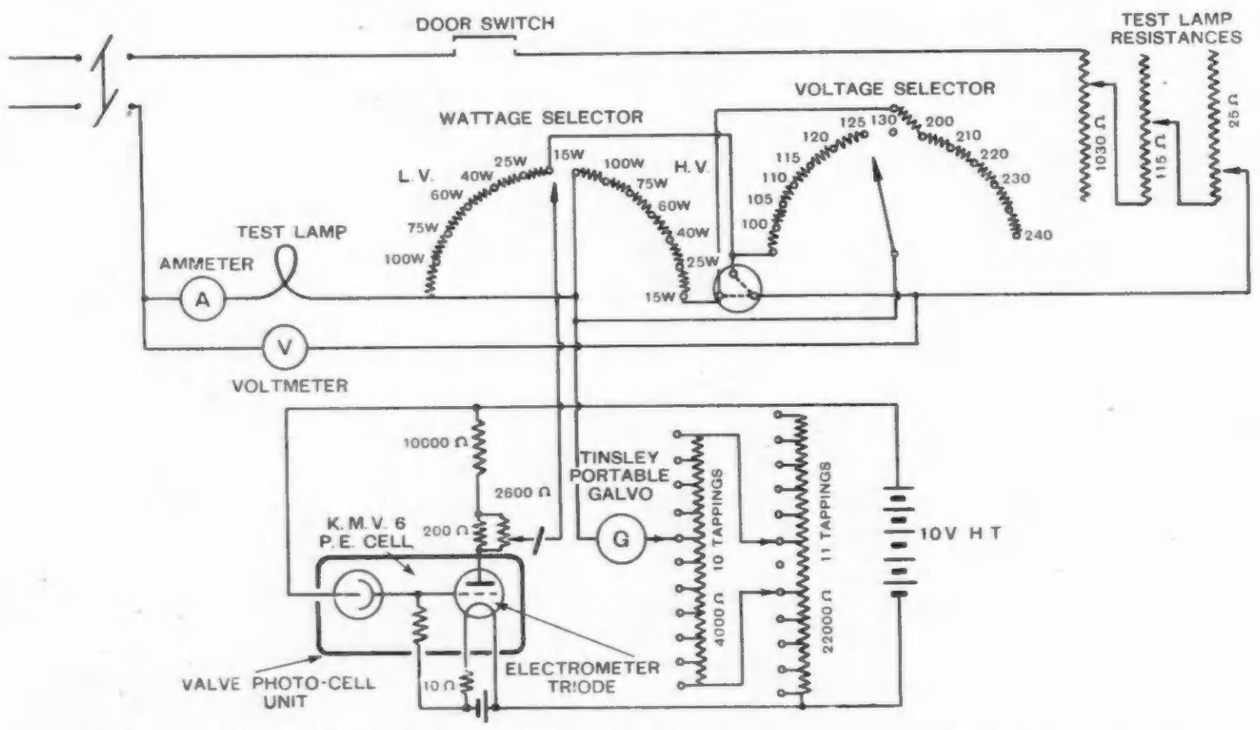

Fig. 7.—Circuit diagram of the latest lumen-per-watt photometer.

In order to utilise this circuit for the measurement of lamps of all ratings, it is necessary to elaborate it to the extent of adding selector switches. This enables suitable values of resistance to be included

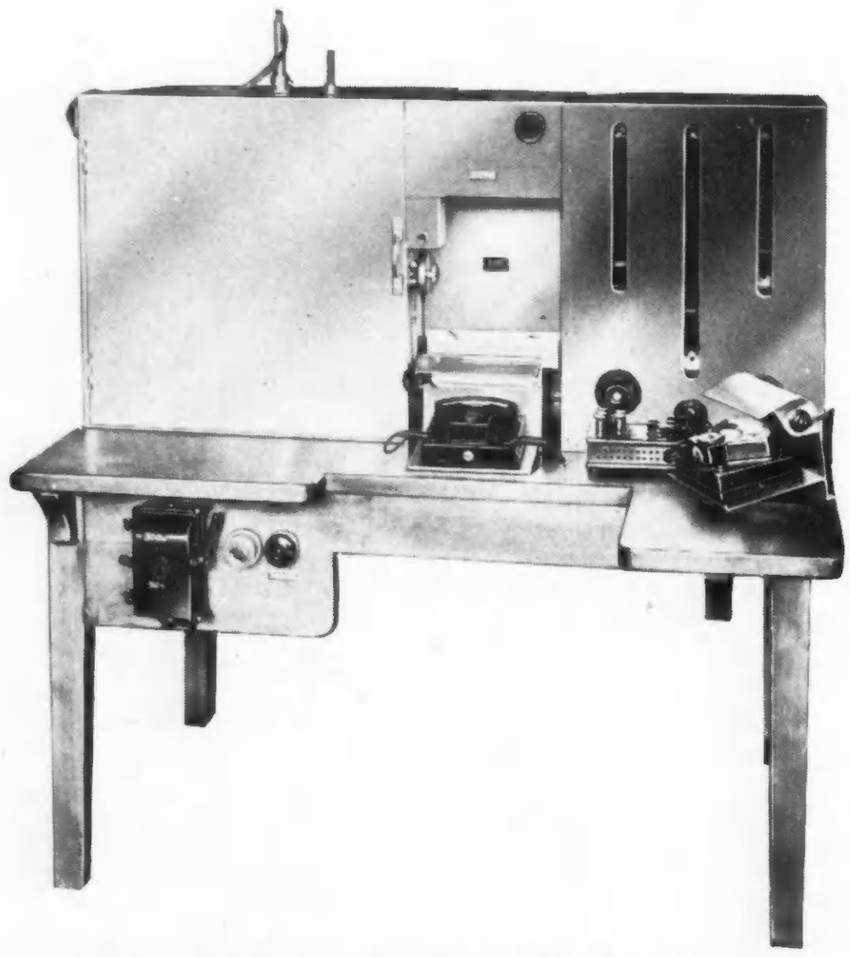

Fig. 8.—Lumen-per-watt photometer with 2 ft. cubical integrator.

in the test lamp circuit so that, irrespective of type size, the same potential will be injected into the amplifier circuit for all lamps having exactly rated lumens and rated watts.

Photometers utilizing this circuit arrangement in conjunction with amplifiers equipped with valve photocell units have been in continuous daily operation in the Osram-G.E.C. Lamp Works for the past three years. The details of the circuit used in these photometers are shown in fig. 7, whilst an illustration of one of the complete lumen per watt photometers having a 2 ft. integrating cube, and suitable for measuring general lighting service lamps from 15 to 100 watts, 100 to 130 and 200 to 260 volt ranges, is shown in fig. 8.

4. IMPROVEMENTS IN LUMEN PHOTOMETERS.

Following the development and construction of the lumen per watt photometers in 1933, the valve photocell unit was incorporated in the design of two new photoelectric photometers for use respectively, in the Osram-G.E.C. Lamp Works, and the G.E.C. Research Laboratories.

It has already been emphasized that the accuracy of the earlier photometers was limited by the instability of the amplifiers. In addition the use of voltmeters for indicating the voltage across the lamp terminals also imposed a limitation on the accuracy attainable.

The new photometers, whilst operating on the same principle as the earlier models, were therefore equipped with the valve photocell unit and with a potentiometer instead of a voltmeter. Considerable care was also exercised in arranging the layout of the controls in order to facilitate accurate and rapid measurement. Fig. 9 is a photograph of one of these photometers suitable for measuring tungsten filament lamps from 10 to 2,000 lumens, but primarily intended for the measurement of general lighting service lamps of 15 to 150 watt rating. The integrator is a sphere 2 ft. 6 in. in diameter, mounted on a control table consisting of a welded angle iron framework, fitted with aluminium panelling. This table contains separate compartments for amplifier, galvanometers, batteries, test lamp resistances and controlling instruments, thus ensuring adequate screening of the components, together with accessibility. The top of the table is covered with black polished bakelite, below which the potentiometers, ammeter and controls are mounted. This enables most of the controls to be mounted flush with the table. It will be noted that the galvanometer associated with the test lamp circuit potentiometer, is so arranged that the spot of the galvanometer is immediately in front of it and facing the operator, whilst that of the amplifier circuit is arranged in front of the "lumen" potentiometer.

There is also a similar design adapted for motor car

and miniature lamps of the low voltage high current types, using an 18 in. integrator.

Diagrams of the test lamp and amplifier circuit are given in figs. 10 (a) and 10 (b).

As in the earlier photometers already referred to, correction is made by means of a colour filter, adjustable over a portion of the aperture between the main and subsidiary integrator, to compensate for the departure of the spectral response of the photocell from that of the internationally agreed "average eye." Using a KMV6 photocell it has always been possible by adjustment to obtain a position of the filter such that the response of the resulting photocell filter combination to light from tungsten filament lamps operating at temperatures from 2,400 to 2,800°K. agrees to within $\frac{1}{4}$ per cent with that which would be obtained by an observer with a hypothetical "average eye."

5. PHOTOELECTRIC PHOTOMETER FOR MEASURING ELECTRIC DISCHARGE LAMPS AND HIGH WATTAGE TUNGSTEN FILAMENT LAMPS.

The development of electric discharge lamps enhanced the difficulties of photometric measurement[8] in terms of existing standards, due to the differences in colour and spectral energy distribution which are involved. After complete study of these photometric problems attention was turned to the design and construction of a photoelectric photometer suitable for measuring the light output of lamps of this class at commercial speeds.

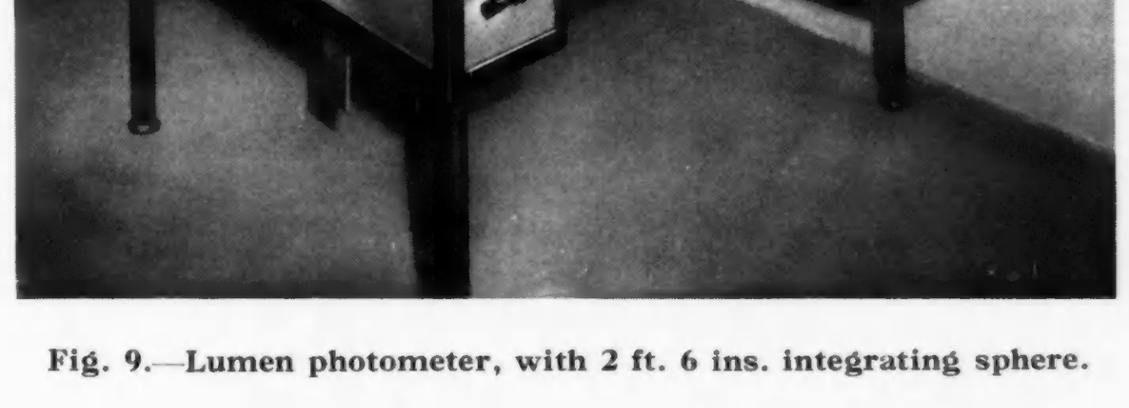

Fig. 9.—Lumen photometer, with 2 ft. 6 ins. integrating sphere.

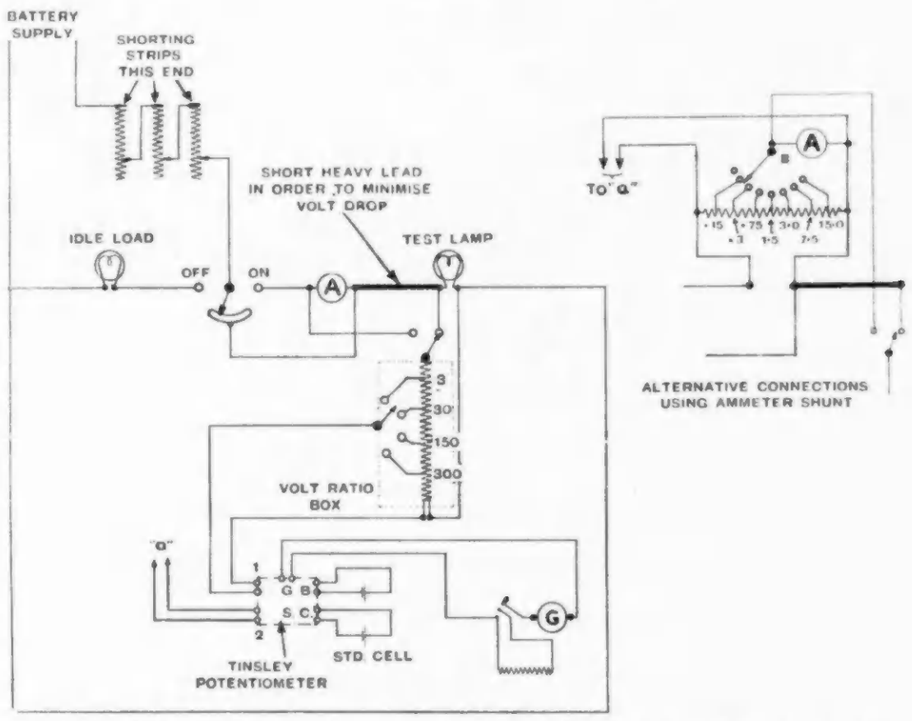

Fig. 10 (a).—Test lamp circuit of lumen photometer.

One of the characteristics of discharge lamps is that some time elapses from the moment of switching on the lamp to the time at which it reaches a state of thermal equilibrium, and the luminous output becomes normal.

This starting time will vary with different makes and types of lamp, but is usually of the order of 5 to 10 minutes. It is clear, therefore, that if it is required to measure such lamps at commercial speeds, apart from other considerations, it will be desirable to provide several idle circuits and some multi-loading gear, so that lamps can be allowed to reach their normal operating temperature before being inserted into the photometric integrator for measurement.

Fig. 11 shows a photometer which was completed

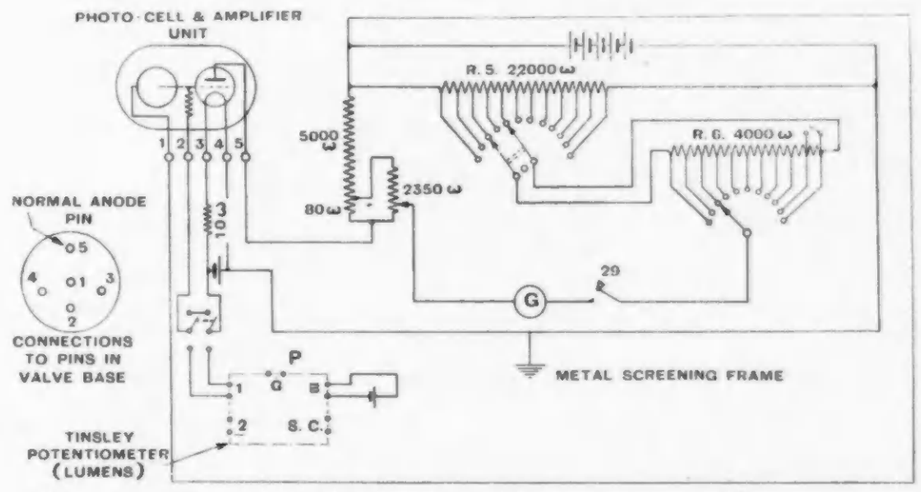

Fig. 10 (b).—Amplifier circuit of lumen photometer.

in December, 1934. A 5 ft. integrating sphere is utilised in this case in order to accommodate the range of lamps for which it was designed, namely electric discharge lamps from 250W. upwards, and tungsten filament general lighting service lamps from 200 to 1,500 watts, also special tungsten filament lamps up to 3,000 watts, such as 50 volt 50 amp. projectors and floodlighting lamps.

The four lamp positions shown on the right hand side of the illustration are so arranged that by means of the converging overhead track the lamps can be run in turn into the centre of the sphere. These

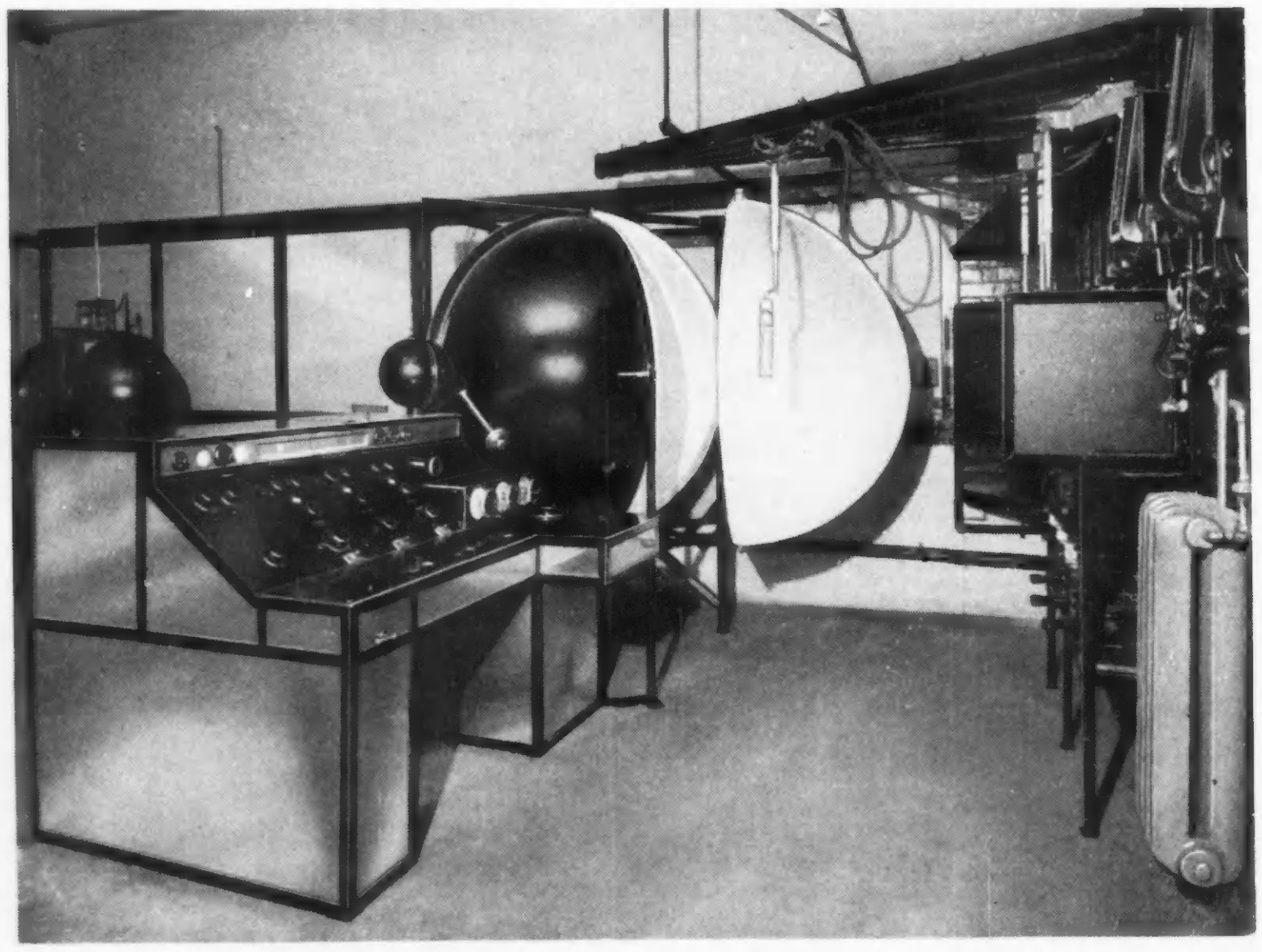

Fig. 11.—A 5 ft. integrating sphere lumen photometer for measuring tungsten filament and gas discharge lamps.

lamp positions, when used for electric discharge lamps, are supplied from 240 volt A.C. mains, *via* suitable chokes arranged beneath the contactors and shown in the illustration on the right hand wall. By an appropriate arrangement of contactors, the circuits to the lamp holders can, by means of an interlocked rotary switch on the control table, be changed in turn, from the idle circuit, on which they are allowed to warm up, to the test lamp circuit which is adjustable from the control table. The electrical measurements on these lamps are made by means of the dynamometer voltmeter, ammeter and wattmeter recessed in the centre of the horizontal portion of the control table. The circuit arrangements will best be understood by reference to the circuit diagram shown in fig. 12.

As this photometer was intended to be suitable for measuring tungsten filament lamps as well as electric discharge lamps, one of the lamp positions is arranged so that it can readily be changed to a D.C. circuit* with suitable controls. The details of this switching arrangement can be seen from the circuit diagram. A potentiometer, located on the left hand side of the sloping panel, is used for the measurement of the voltage on the test lamp. The centre potentiometer, which is calibrated directly in lumens, supplies to the D.C. amplifier circuit the grid bias necessary to restore balance, as

* This can be supplied either by a battery or a suitable motor-generator set. The use of a motor generator has been found in industrial practice to be best for lamps of high wattage, and is also better than a battery for lamps of lower wattages unless a separate battery is available for each photometer. See G.E.C. Journal, Vol. III., No. 3, August, 1932.

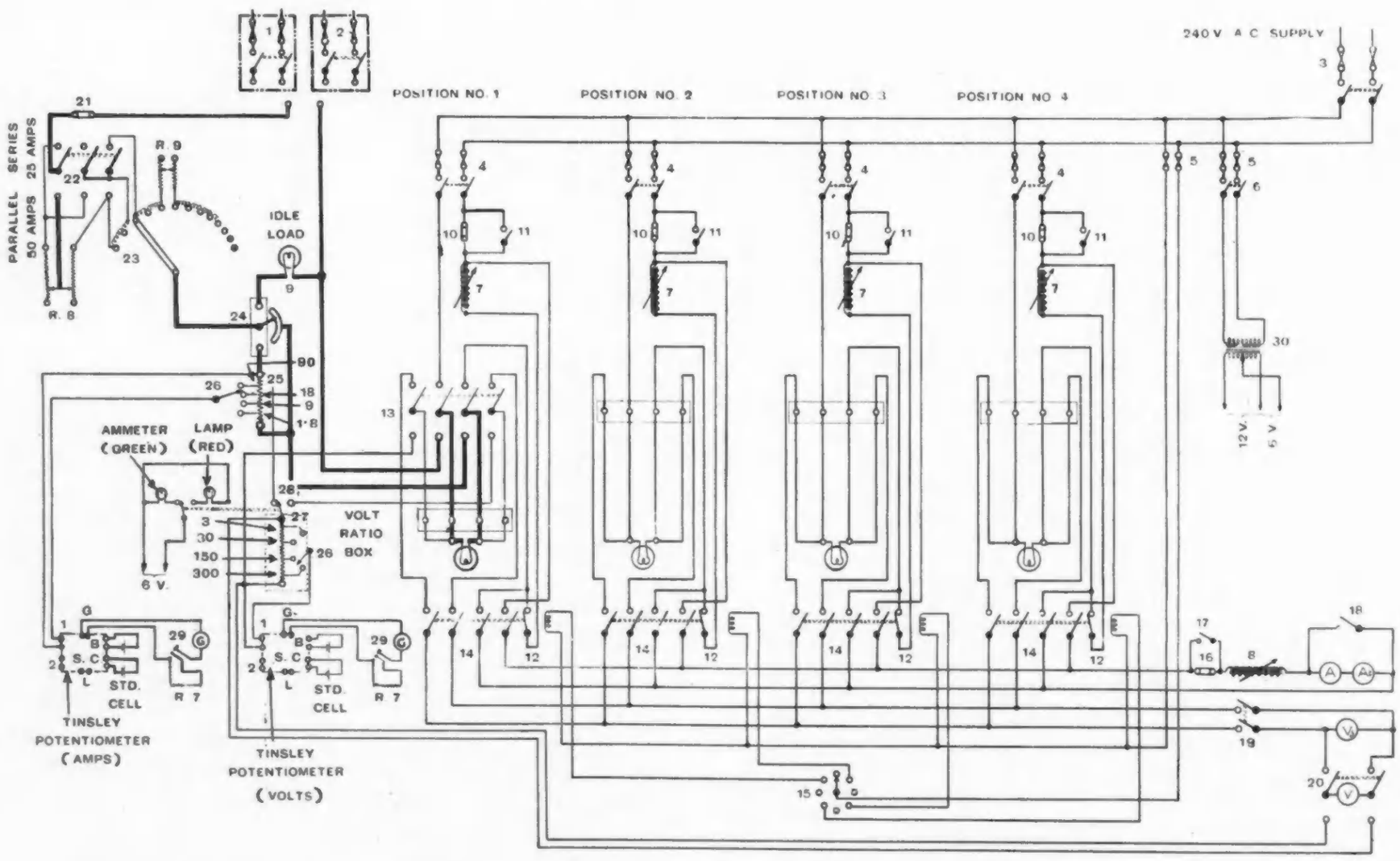

Fig. 12.—Circuit diagram of test lamp and idling circuits of 5 ft. sphere lumen photometer.

indicated by the galvanometer. In these respects the circuit arrangements are the same as in the 2 ft. 6 ins. integrating photometer, the diagram of which is in fig. 10 (b). A third potentiometer on the right hand side of this panel displaces the usual ammeter, and enables the current of the test lamp to be measured while the voltage is held constant by means of the "voltage" potentiometer. The three keys of the respective galvanometer circuits are grouped together on the left hand side of the table, so that they can be conveniently controlled by the fingers of one hand. As all three galvanometers can be observed simultaneously, uncertainties are avoided as to the correctness of the voltage at the time the lumens and current indications are noted.

In this photometer, as in the one with the 2 ft. 6 ins. integrator, the arrangement of the valve photocell unit in a D.C. amplifier has been adopted, as well as the micrometer shutter for controlling the light entering the subsidiary integrator, and the filter slide to enable the portion of the filter covering the aperture to be adjusted in order to control the spectral sensitivity of the apparatus.

It was anticipated that the adjustable filter arrangement used in the earlier photometers, which had proved satisfactory for all tungsten filament lamps, would not be satisfactory for use when measuring electric discharge lamps. A new three colour filter was therefore developed, which is housed in a similar slide but fitted with an additional shutter. The effective areas of each of the three filters can thus be adjusted. Using this three colour filter arrangement a much better approximation to the "average eye" sensitivity is obtained than had previously been possible.

By adjustment with respect to standard tungsten filament lamps operating at different temperatures and also electric discharge lamps of different types, it has been found possible to correct the photocell sensitivity so that the errors introduced when measuring tungsten filament lamps operating at temperatures from 2,400 to 3,000°K. are negligible. On the same calibration the error in the case of H.P. mercury electric discharge lamps is of the order of 5 per cent. As the percentage errors in the latter case are comparatively small, and constant for the respective types of discharge lamp, suitable adjustments can readily be made by means of the micrometer shutter, so that the lumen scales in all cases can be made direct reading.

6. OTHER APPLICATIONS OF THE VALVE PHOTOCELL UNIT.

As has already been shown the valve photocell unit has proved very useful where it has been required to make precise measurements of light intensity. More especially is this the case where only small amounts of luminous flux are available, and in consequence a high degree of stable amplification is required.

A universal photometer, first shown at the Physical Society Exhibition in January, 1934, in conjunction with an apparatus for measuring the linearity of response of photocells, was built for use in connection with the many experimental problems requiring apparatus of this type.

A photograph of this universal type of photometer is shown in fig. 13.

The arrangement of the component parts can be seen from a photograph taken with the cover removed (fig. 14). The circuit of this amplifier is similar to that of the photometers described in the foregoing sections and shown in fig. 10 (b).

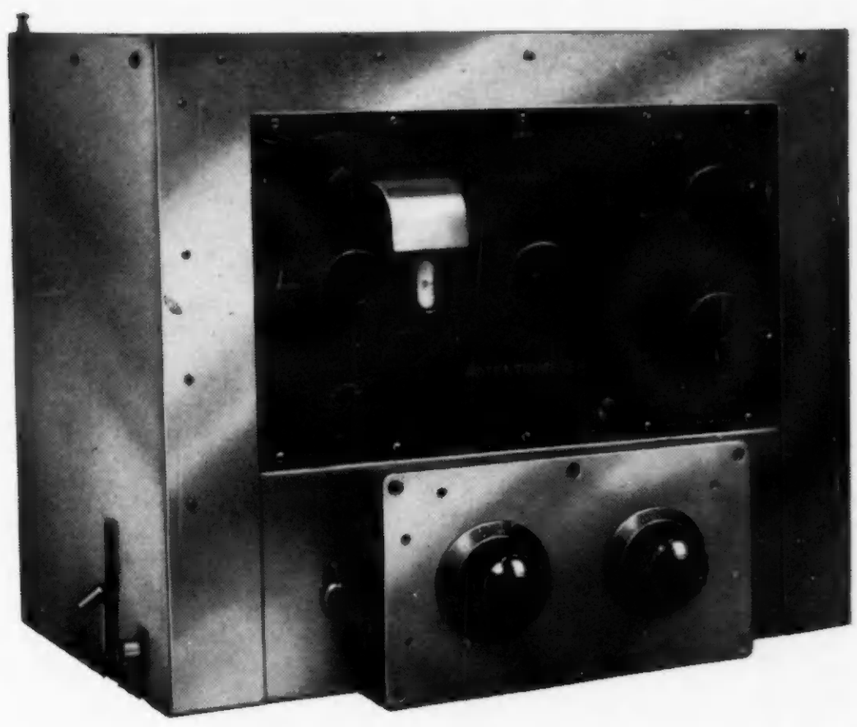

Fig. 13.—Control panel of universal photometer.

This photometer has been used at the G.E.C. Research Laboratories in conjunction with a monochromatic illuminator for measuring to high precision the spectral transmission of colour filters. It has proved possible for example to take a set of equal energy transmission measurements at 20 wavelength intervals throughout the visible spectrum, to an accuracy of 0.5 per cent in about ½ hour. This has been particularly useful in connection with problems of heterochromatic photometry[8] where it is required, by means of filters of known spectral transmission, to reduce to a minimum the colour difference between the various types of electric discharge lamps and the tungsten filament lamps in which the present unit of white light is held. With a high sensitivity valve photocell unit in this apparatus relative total radiation measurements have been made in experimental determinations, by direct comparison of the relative luminosity of light sources differing very appreciably in spectral energy distribution.

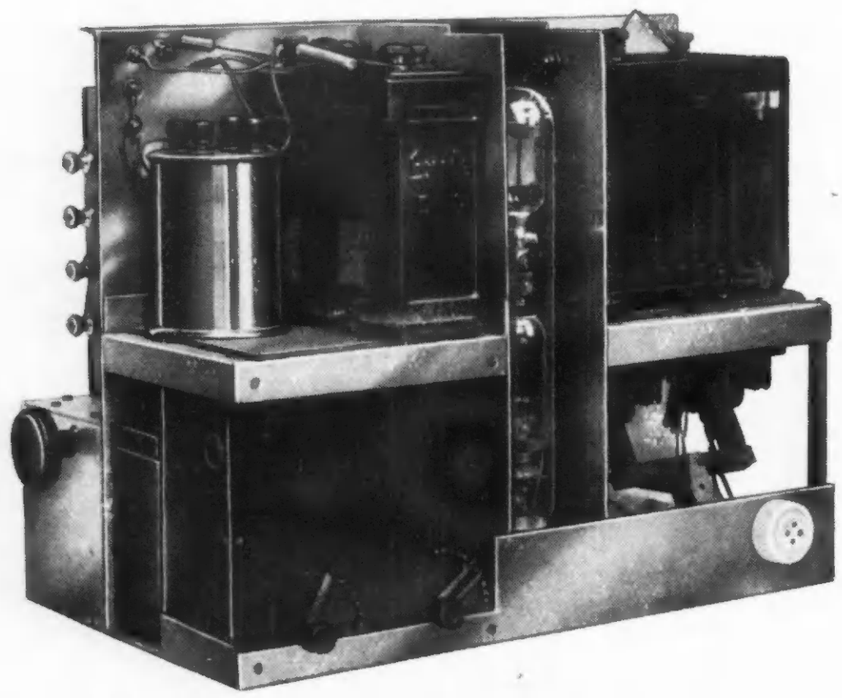

Fig. 14.—Universal photometer—internal arrangements.

This photometer was also used in an extended investigation into the time of nigrescence and incandescence of tungsten filament lamps[9] of various types, and for the measurement of directional candle power and candle power distribution, particularly of low power sources.

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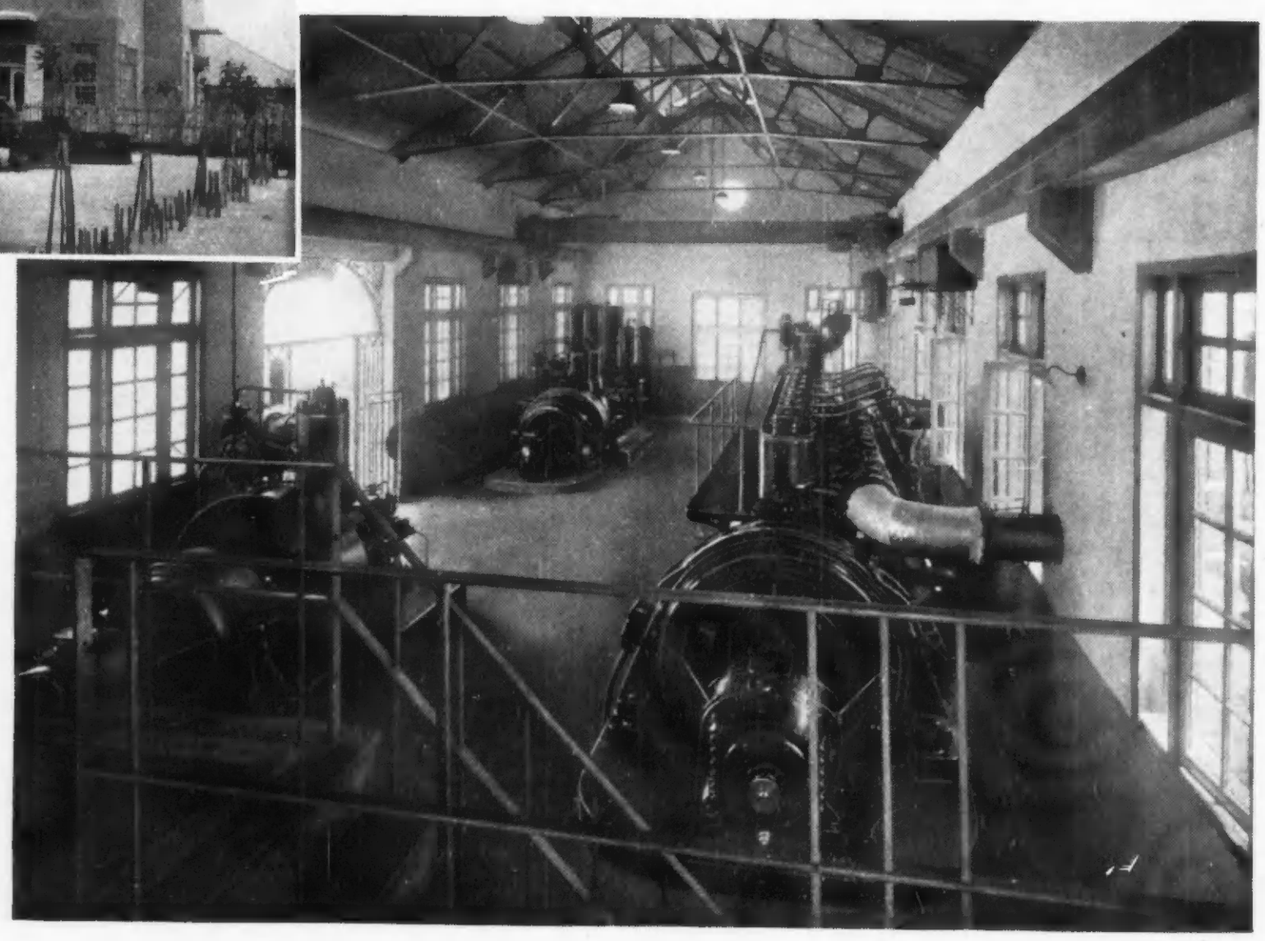
(6) British Patent No. 356944.
(7) G. T. Winch and C. T. Harper, G.E.C. Jour., Vol. 3, No. 3, Aug., 32.
(8) H. Buckley, Ill. Eng., April and May, 34, and
G. T. Winch, E. H. Palmer, C. F. Machin and B. P. Dudding, G.E.C. Jour., Vol. 5, No. 3, Aug., 34.
P. D. Oakley, Ill. Eng., June 35.
(9) J. M. Sandford and J. M. Waldram, Ill. Eng., Vol. 28, p. 109, April, 35.

Electrical Equipment for the Kulangsu Chunghua Electric Co.

Exterior and interior views of the new power station of the Kulangsu Chunghua Electric Co., of Amoy, China. This station replaces the old power house which was burnt out in October, 1933. The generating plant installed comprises four oil-engine-driven alternators totalling 600 kW in capacity, generating at 2,300 volts, 3 phase, 50 cycles. A cubicle steelplate switchboard controls the outgoing feeders.



Distribution is made by a 2,300 volt overhead system, over 30 pole-mounted transformers of 5 to 25 kVA having been installed to step down the supply voltage to 220 volts. In addition, a total of 1,500 meters have been supplied for metering the supply to consumers' premises.

Turbo-Blowers and Turbo-Compressors.

PART II.

By B. POCHOBRADSKY M.I.Mech.E.

Chief Engineer, Fraser & Chalmers Engineering Works, Erith.

MULTISTAGE COMPRESSOR.

IN a compressor consisting of a number of stages working in series, each of the stages has obviously a certain characteristic relation between the manometric coefficient μ and the volumetric coefficient δ; in the first stage the gas volume at its inlet is quite unaffected by subsequent work in the compressor; the performance of the next stage depends, however, not only on the gas volume at the inlet of the first stage, but also on the variation of the specific volume effected by compression in the first stage, which again depends on the $\mu - \delta$ characteristic of the first stage, the peripheral speed of the first stage and the stage losses. Similarly, any later stage will depend not only on the gas volume at the inlet to the first stage, but also on the variation of the specific volume of the gas caused by the compression in the preceding stages. The examination of the $\mu - \delta$ characteristic of a multistage compressor is therefore somewhat complicated, yet it is important, as the $\mu - \delta$ characteristic of one stage does not represent the $\mu - \delta$ characteristic of a multistage machine.

In order to simplify the considerations, a certain normal speed for our machine will be assumed and a certain normal inlet gas volume for which the machine was designed; it will further be assumed that at this normal speed and normal gas volume μ is the same for all stages and also that the $\mu - \delta$ characteristic is the same for all the stages when, of course, δ of the various stages refers to the gas volume at each particular stage. Let the manometric coefficient μ for the normal gas volume and normal speed be μ_n

For one stage it was given in formula (17):

$$\mu_n = \frac{\Delta H_{ad}}{A\, u_2^2 \frac{1}{g}}$$

For a multistage machine,

$$(19) \qquad \mu_n = \frac{\Sigma\,(\Delta H_{ad})}{A\, \frac{1}{g}\, \Sigma\,(u_2^2)}$$

In fig. 10 is traced μ of one stage and μ_m of a multistage machine in function of δ of the first stage. Keeping the speed constant and increasing the inlet volume so that δ of the first stage reaches the value δ_1, it will be seen that μ for δ_1 is smaller, as a result of which there will be smaller adiabatic compression in the first stage, though K_s (see

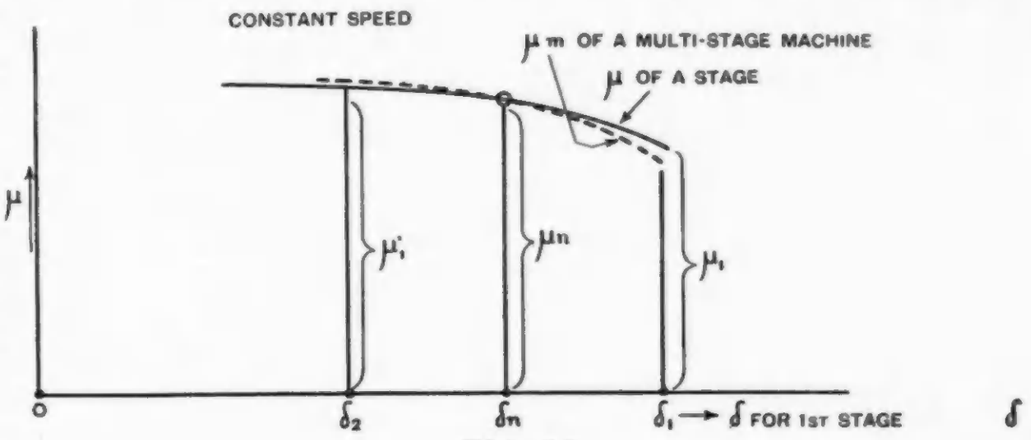


Fig. 10.

fig. 7) is greater. In other words, the specific volume at the inlet of the second stage will be greater with the increased inlet gas quantity. This means that δ of the second stage is greater than δ_1 of the first stage: hence μ_2 of the second stage will be smaller than μ_1, and for similar reasons μ_3 for the third stage will be smaller than μ_2, etc. Thus a gradual reduction of μ occurs in the successive stages. Similarly, if the gas volume is reduced at the inlet of the machine so that δ of the first stage reaches the value δ_2, it will be seen that μ_1' is greater than μ_n; there is greater adiabatic compression, while K_s (see fig. 7) is smaller. The specific volume at the inlet of the second stage will be smaller; hence δ of the second stage will be smaller than δ_2 and therefore μ_2' of the second stage greater than μ_1'.

The sum of adiabatic heat increases for the increased gas quantity in the multistage machine will be

$$\Sigma\, \Delta H_{ad1} = \frac{A}{g}\, \Sigma \left(\mu\, u_2^2 \right)_1 = \frac{A}{g}\, \mu_{m1}\, \Sigma\, u_2^2$$

and for reduced gas quantity

$$\Sigma\, \Delta H_{ad2} = \frac{A}{g}\, \Sigma \left(\mu\, u_2^2 \right)_2 = \frac{A}{g}\, \mu_{m2}\, \Sigma\, u_2^2$$

where μ_{m1} and μ_{m2} are manometric coefficients for the whole multistage machine with gas quantities respectively greater or smaller than the normal

quantity. As μ for greater gas quantity gradually decreases in the successive stages

$$\mu_{m1} < \mu_1$$

and as μ for smaller gas quantity gradually increases in successive stages

$$\mu_{m2} > \mu_1'.$$

In other words, the μ_m for the multistage machine at a given speed is steeper than μ for a single stage

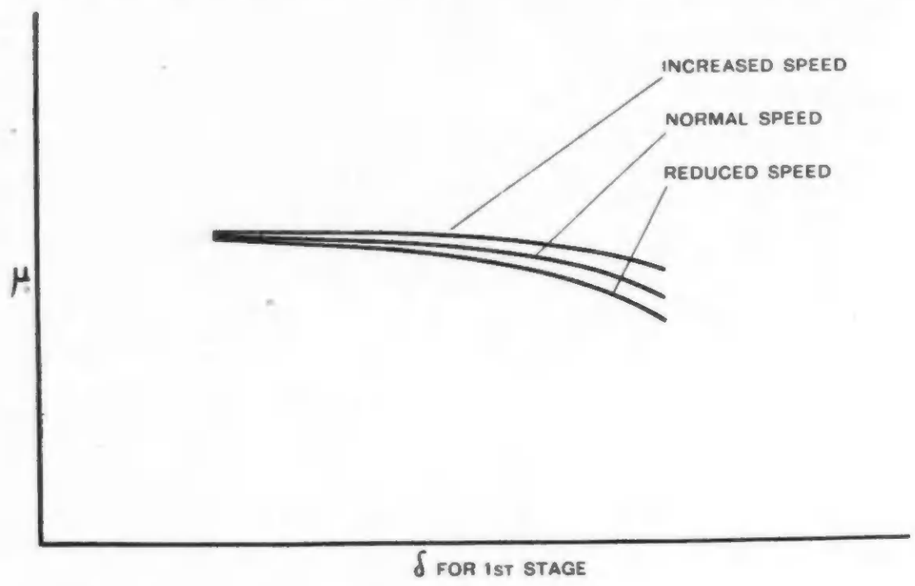


Fig. 11.

(see fig. 10) and the steepness will grow with increase in the number of stages.

It is important to consider the effect of speed on the $\mu-\delta$ characteristic of a multistage machine. The same assumptions are made as in the foregoing discussion, but the speed is increased from n to n_1 and the inlet gas quantity in the ratio $\frac{n_1}{n}$ so that for the first stage the $\mu-\delta$ characteristic is identical to the full line in fig. 10.

By increasing the speed greater compression and smaller specific volume are obtained at the inlet of the second stage; hence δ of the second stage will be smaller, and μ higher. Similarly there will be a gradual increase of μ in the successive stages due to increased speed. With still larger inlet gas quantity, the gradual increase of μ in successive stages on account of increased speed will be more pronounced because in the region of larger inlet volumes μ increases more rapidly with the reduced specific volumes in the successive stages.

With reduced speed the specific volume in the successive stages is increased: hence δ is increased and μ reduced. Fig. 11 illustrates the effect of the variation in speed on the $\mu-\delta$ characteristic of a multistage machine.

It will be seen from the foregoing observations that the $\mu-\delta$ characteristic (where δ refers to the first stage) of a multistage machine depends not only on the stage $\mu-\delta$ characteristic but also on the number of stages and on the speed.

It has already been shown that in an uncooled machine, the losses in each stage appear as heat in the gas (see also fig. 5); hence the sum of the adiabatic heat increases of the total heat in 1 lb. of gas for all stages is greater than the adiabatic heat increase between the pressure and temperature at the inlet of the first stage and the pressure at the outlet of the last stage.

In a cooled machine the sum of the adiabatic heat increases for all stages is reduced compared with an uncooled machine and may, for medium and higher pressures and with good cooling, become less than the adiabatic heat increase between the initial pressure and temperature and the final pressure. If therefore μ of a multistage machine is referred to the adiabatic heat increase from the pressure and temperature at the inlet of the first stage to the pressure at the outlet of the last stage, this factor has to be taken in consideration. As an example μ calculated in this way for an uncooled machine will be smaller than μ referred to the sum of actual adiabatic heat increases in all stages.

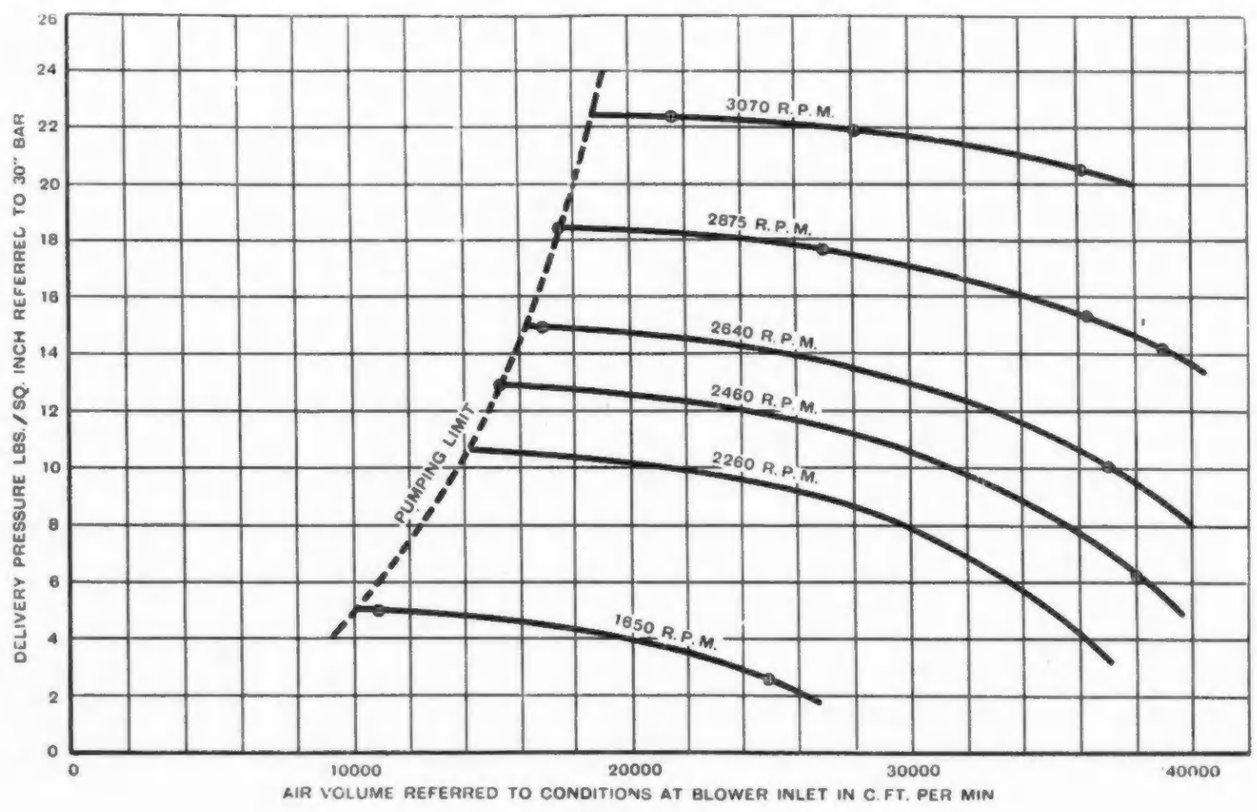


Fig. 12.

It may be mentioned that μ as discussed above does not include the losses in the intake and delivery of machine.

Having discussed the characteristic of a multistage machine, two examples may now be given in which the characteristic is shown in a form suitable for immediate practical purposes, namely pressure as a function of intake volume.

Fig. 12 shows pressure as a function of the gas volume at the inlet of a Fraser & Chalmers uncooled turbo-blower at different speeds and fig. 13 is a

pressure-volume diagram of a Fraser & Chalmers cooled turbo compressor.

MOISTURE IN THE GAS.

The gas may be a mixture of several gases; if one of these gases is water vapour we speak of the mixture as a "wet gas."

Assuming a volume of 1 cu. ft. filled with a gas at an absolute pressure p_1 lb./sq. in. and a temperature t °F. (abs. temperature $T = 459.58 + t$) and another gas filling also a volume of 1 cu. ft. at an absolute pressure p_2 and the same temperature t, then

$$p_1 = \gamma_1 R_1 T$$
$$p_2 = \gamma_2 R_2 T$$

where γ is the specific weight in lbs./cu. ft. and R the gas constant.

If these two gas weights γ_1 and γ_2 be mixed in a total volume of 1 cu. ft. at the same temperature t, the weight of the mixture

$$\gamma_m = \gamma_1 + \gamma_2$$

and the gas constant of the mixture

$$R_m = \frac{R_1 \gamma_1 + R_2 \gamma_2}{\gamma_1 + \gamma_2}$$

For the mixture,

$$p_m = \gamma_m R_m T = \left(\gamma_1 + \gamma_2\right) \frac{R_1 \gamma_1 + R_2 \gamma_2}{\gamma_1 + \gamma_2} T$$
$$= p_1 + p_2$$

which expresses Dalton's law; p_1 and p_2 are the partial pressures of the two gases constituting the mixture.

In the case of water vapour being one of the components of the mixture the partial pressure of the water vapour cannot exceed the saturation pressure p_s corresponding to the temperature t of the mixture; it follows that the maximum possible weight of water vapour contained in 1 cu. ft. of gas (the gas is then saturated) is equal to the specific weight of water vapour γ_s at the temperature t. For saturated gas we can write:

$$p_m = p_g + p_s$$
$$\gamma_m = \gamma_g + \gamma_s$$

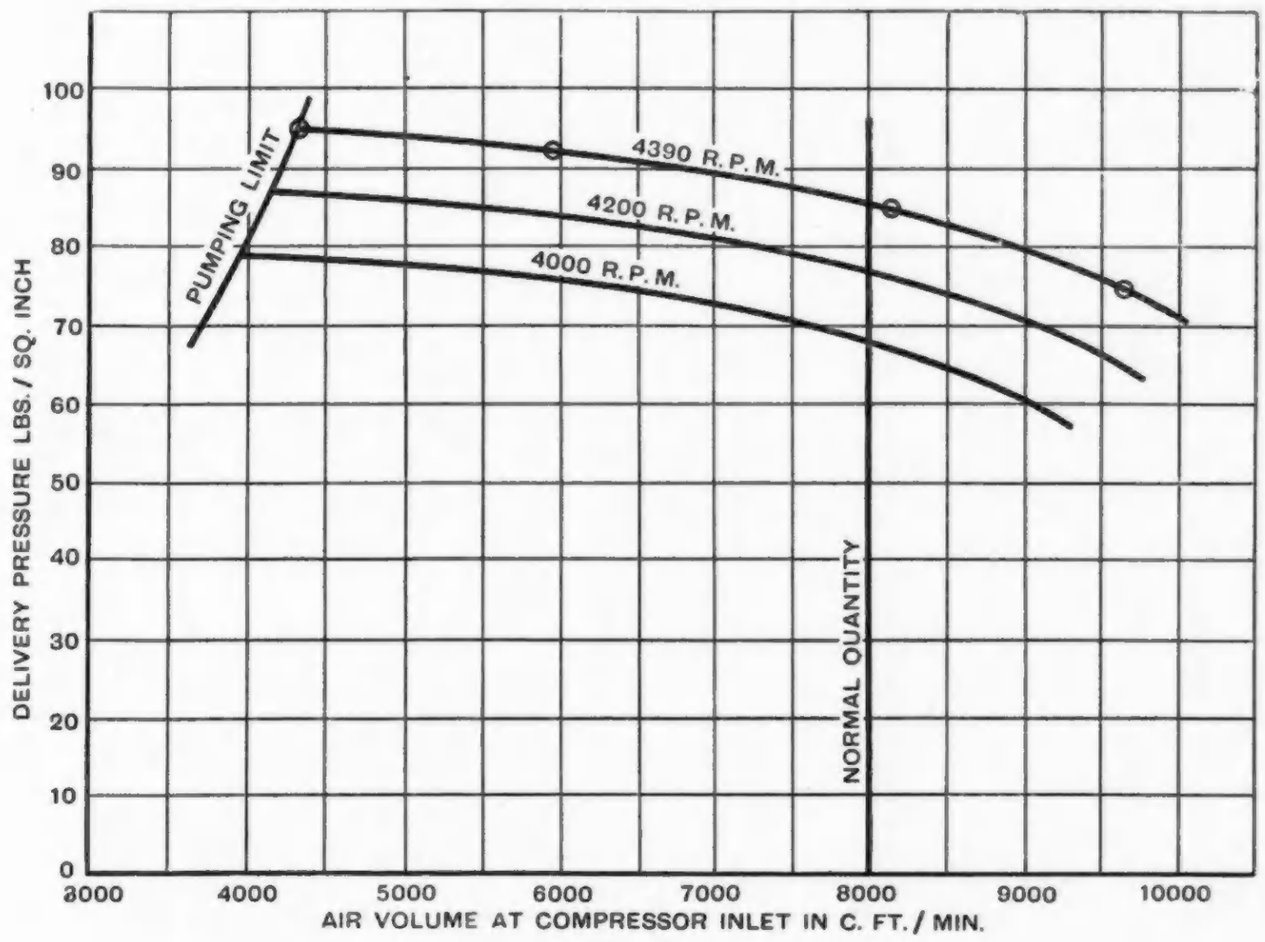


Fig. 13.

when p_m = abs. pressure of the saturated gas.
p_g = partial abs. pressure of the dry gas.
p_s = saturation pressure of water vapour at temperature t.
γ , γ_g, γ_s = specific weight of saturated gas, dry gas and water vapour respectively.

p_g can now be calculated for any pressure p_m and temperature t of the saturated gas with the aid of steam tables, where we find p_s and γ_s for the temperature t:

$$p_g = p_m - p_s$$

p_g and t determine γ_g; then

$$\gamma_m = \gamma_g + \gamma_s$$

As γ_m lbs. of saturated gas contains γ_s of water vapour, then 1 lb. of saturated gas contains $\frac{\gamma_s}{\gamma_m}$ lbs. of water vapour (moisture).

The diagram fig. 14 showing the moisture content of saturated air for different temperatures and absolute pressures was established in this manner. With the aid of this diagram a casing cooled compressor can be compared with a compressor provided

with intercooling. In fig. 15 is plotted curve "A" showing the air temperature at different pressure points in a casing cooled compressor. The zig-zag line "B" shows the air temperature in a compressor with intercoolers (the temperature falls corresponding to the points at inter-coolers). Curve "C" indicates the temperature at which the air remains saturated right through the compressor if it were saturated at the compressor inlet.

At temperatures below the curve "C" the moisture would be partially condensed, above it the air is not saturated, and is capable of taking up more moisture (to evaporate entrained water). It is seen that in a casing cooled compressor the initial moisture content remains unaffected. In a compressor with intercoolers, while at inlet (assuming saturated air at 60°F. and 14.7 lbs./sq. in. abs.) there is .0103 lbs. of moisture per 1 lb. of air, in the last intercooler the moisture content is reduced by condensation to .006 lbs., or to almost half of the original moisture content.

Moisture in the compressed air causes greater wear in pneumatic machines and tools, and in the cases where such appliances are used in deep, hot mines, the moisture content adds greatly to the discomfort of the miners. For these reasons efforts are made to de-humidify the compressed air used in mines.

Referring to fig. 14, it will be seen, for instance, that if saturated air compressed to 95 lbs./sq. in. abs. is cooled (in an after-cooler) to 80°F., the moisture content is reduced to about .003 lbs. per 1-lb. of saturated air; if the temperature of the compressed air (95 lbs./sq. in. abs.) is reduced to, say, 40°F., its moisture content is reduced to about .0005 lbs. per 1 lb. of air. Such intensive cooling can be achieved by refrigerating plant or by extracting heat out of the air by obtaining power out of it. This latter scheme has found favour in some South African mines. It will at once be apparent from Fig. 14 that de-humidification will be more pronounced at high pressures than at lower pressures: the air temperature should be kept just a little above the freezing point in any case. At 40°F., for instance, the moisture content is about .0005 lb. at 95 lbs./sq. in. abs. and about .0043 lbs. at 14.7 lbs./sq. in. abs., *i.e.*, more than eight times greater.

For de-humidification the compressed air from a compressor or an aftercooler is compressed to a higher pressure than required in the mine, cooled again at this higher pressure and then used in an air motor (for instance an air turbine) in which the air would be expanded to the pressure required in the mine and cooled by the extraction of useful work. The condensed moisture has of course to be separated. It is clear that such de-humidifying plant can be

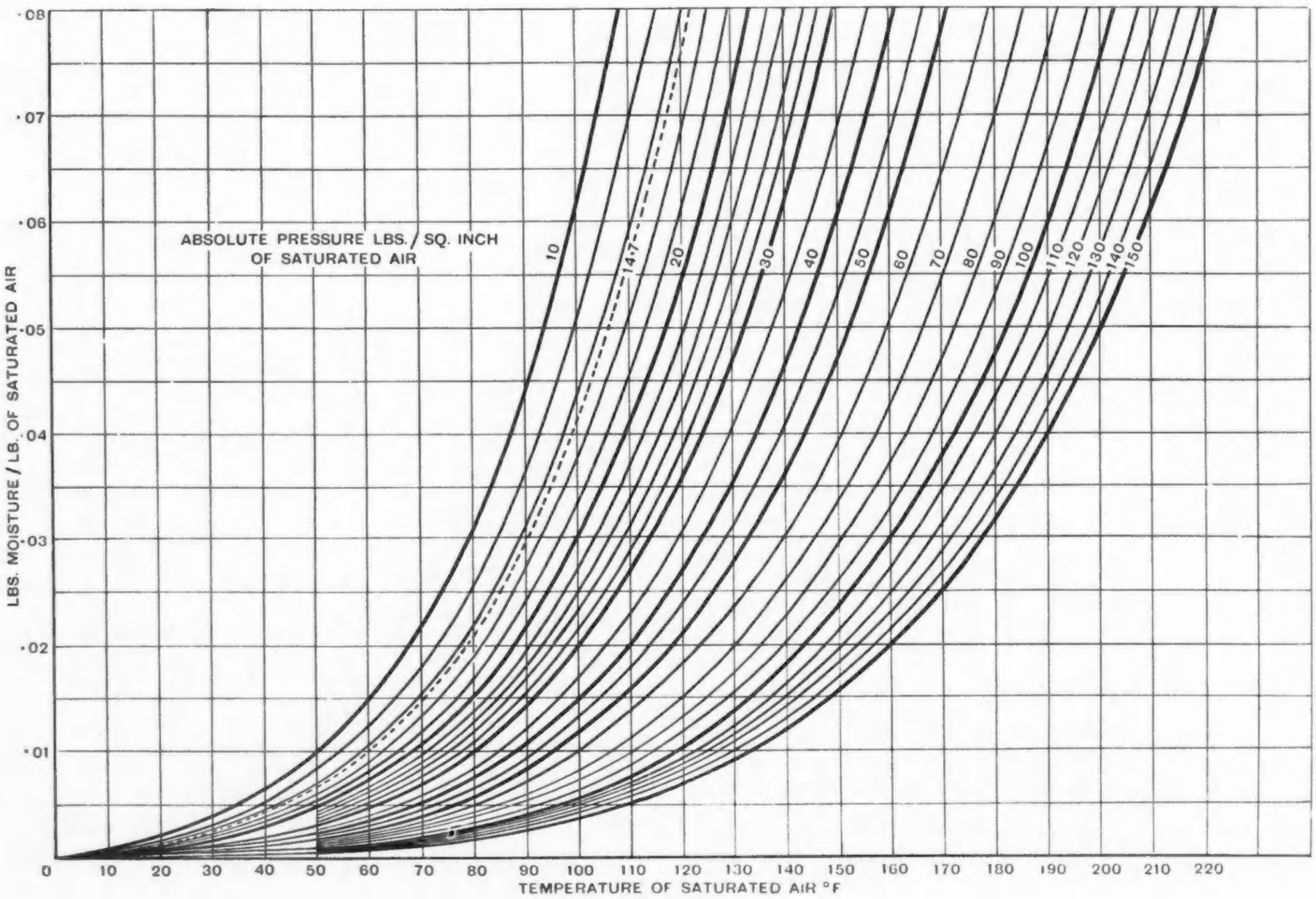


Fig. 14.

incorporated in the main compressor. Naturally the air motor cannot give the output required for super compression, because it works within a lower temperature range than the super compressor. The difference in power due to the difference in temperature range as well as the losses in the air motor and super compressor have to be covered by some other power supply.

GENERAL DESIGN.

Turbo-blowers are designed with either single flow or double flow. Where large quantities of gas at comparatively low pressures are required, a double flow turbo blower may be applied with advantage. An example of this type of machine is given in fig. 17.

In course of years the peripheral velocity of impellers has been steadily increasing. While twenty-five years ago the impellers of turbo-blowers reached a peripheral velocity u_2 of about 500 ft./sec., to-day a velocity of 800 ft./sec. has become practical, due to improved design and materials used for the impellers. As the volumetric coefficient

$$\delta = \frac{Q_1}{u_2 D_2^2} = \frac{Q_1}{\pi \,.\, RPS. \, D_2^3},$$

it is seen that the volumetric capacity of a given impeller (or given D_2) has been increased in the ratio $800/500 = 1.6$ times; at the same time the adiabatic heat increase is raised in the ratio $\frac{800^2}{500^2} = 2.56$ times, and the total work of the impeller increased 4.1 times.

If, on the other hand, the speed r.p.s. is kept the same and the peripheral velocity increased by means of increased diameter (1.6 × original D_2) then the volumetric capacity is increased $1.6^3 = 4.1$ times and the compression work per 1 lb. of gas 2.56 times or the total work of the impeller with the increased diameter is increased 10.5 times.

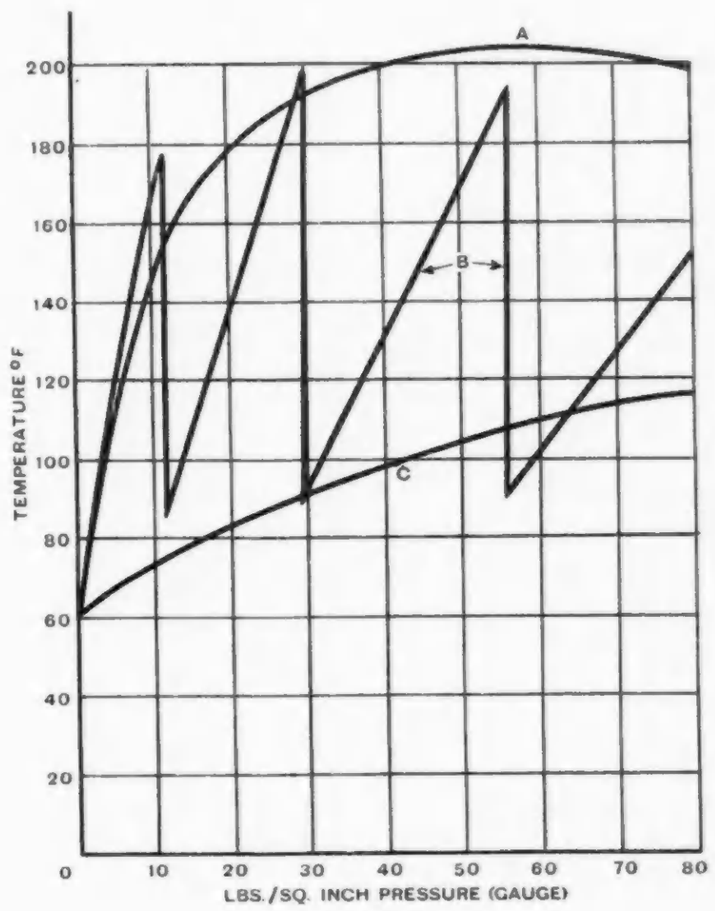


Fig. 15.

Of course the increased peripheral velocity may be obtained by increasing partly the speed and partly the diameter.

These conditions explain why in modern machines single flow is predominant, and fig. 16 shows in section a 4-stage single flow turbo blower, capable of dealing with 50,000 cu. ft. of air per min. against a pressure of 20 lb./sq. in.

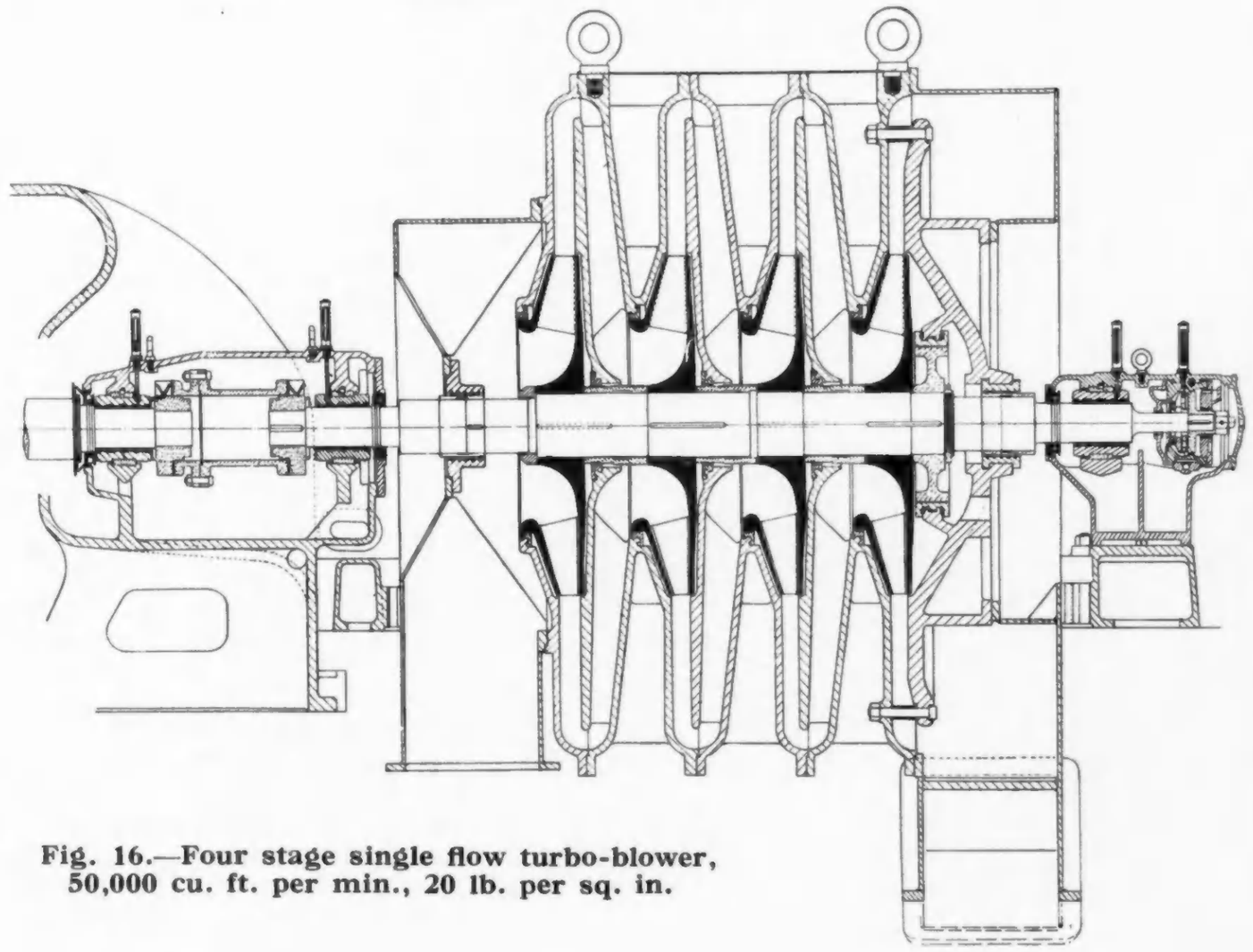


Fig. 16.—Four stage single flow turbo-blower, 50,000 cu. ft. per min., 20 lb. per sq. in.

Each impeller of this turbo-blower consists of a main disc pressed and keyed on the shaft, a side plate of forged high tensile alloy steel and machined blades riveted to the main disc and side plate. Labyrinth glands are provided round the eye of each impeller. A balancing piston, which reduces the longitudinal thrust of the rotor to a small figure, is mounted after the last impeller, and the residual thrust is taken up by a Michell thrust bearing mounted at the end of the shaft. The balancing piston is provided with labyrinth packing, and the space after

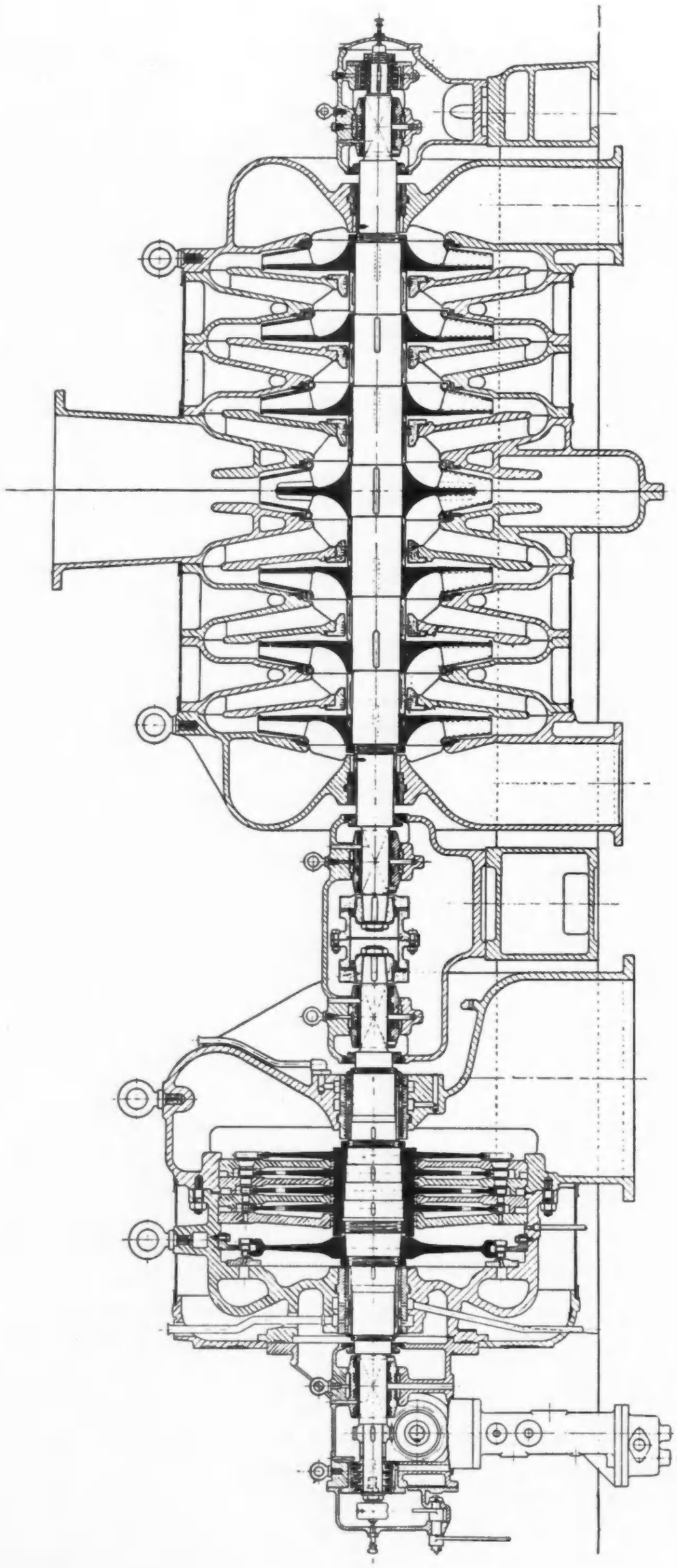


Fig. 17.—Four stage double flow turbo-blower, 30,000 cu. ft. per min., 12 lbs. per sq. in. This machine was installed in 1913.

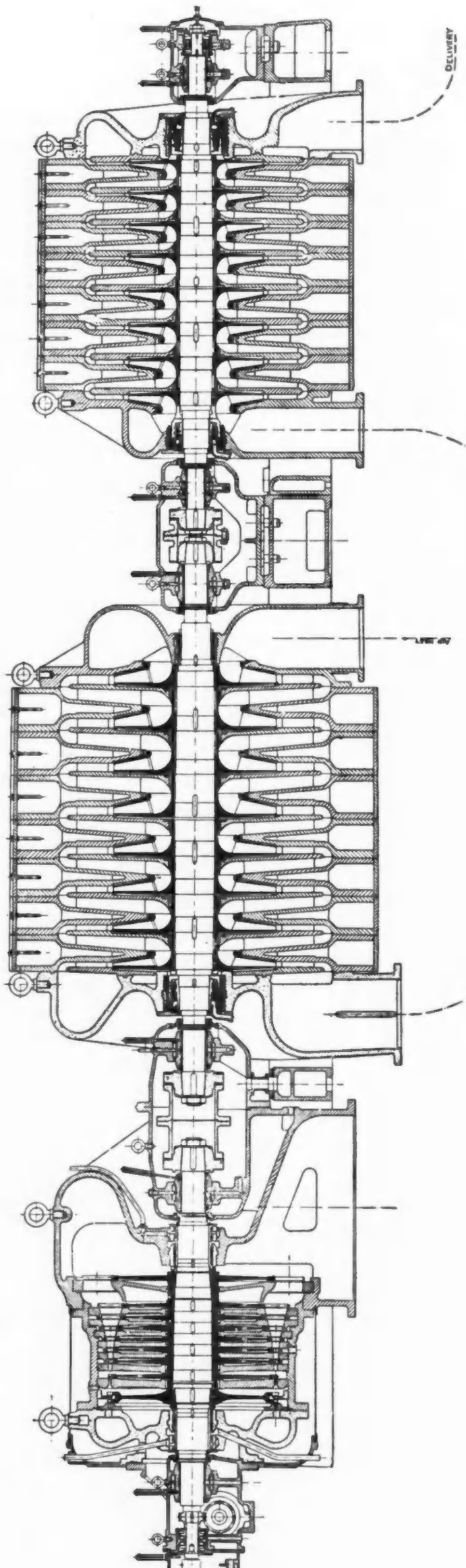


Fig. 18.—Two casing turbo-compressor, 25,000 cu. ft. per min., 110 lbs. per sq. in. This machine was installed in 1918.

it is connected to the blower inlet. The casing, which is divided into top and bottom parts bolted together along the centre horizontal joint, comprises an inlet and outlet, both of welded steel, together with separate castings forming the diffusers, return channels and chambers for impellers. The castings are bolted together along circular joints. The rotor is carried by two main bearings, and the casing inlet and outlet, where the shaft passes through, are provided with labyrinth packings to prevent air being sucked from, or delivered into, the engine room.

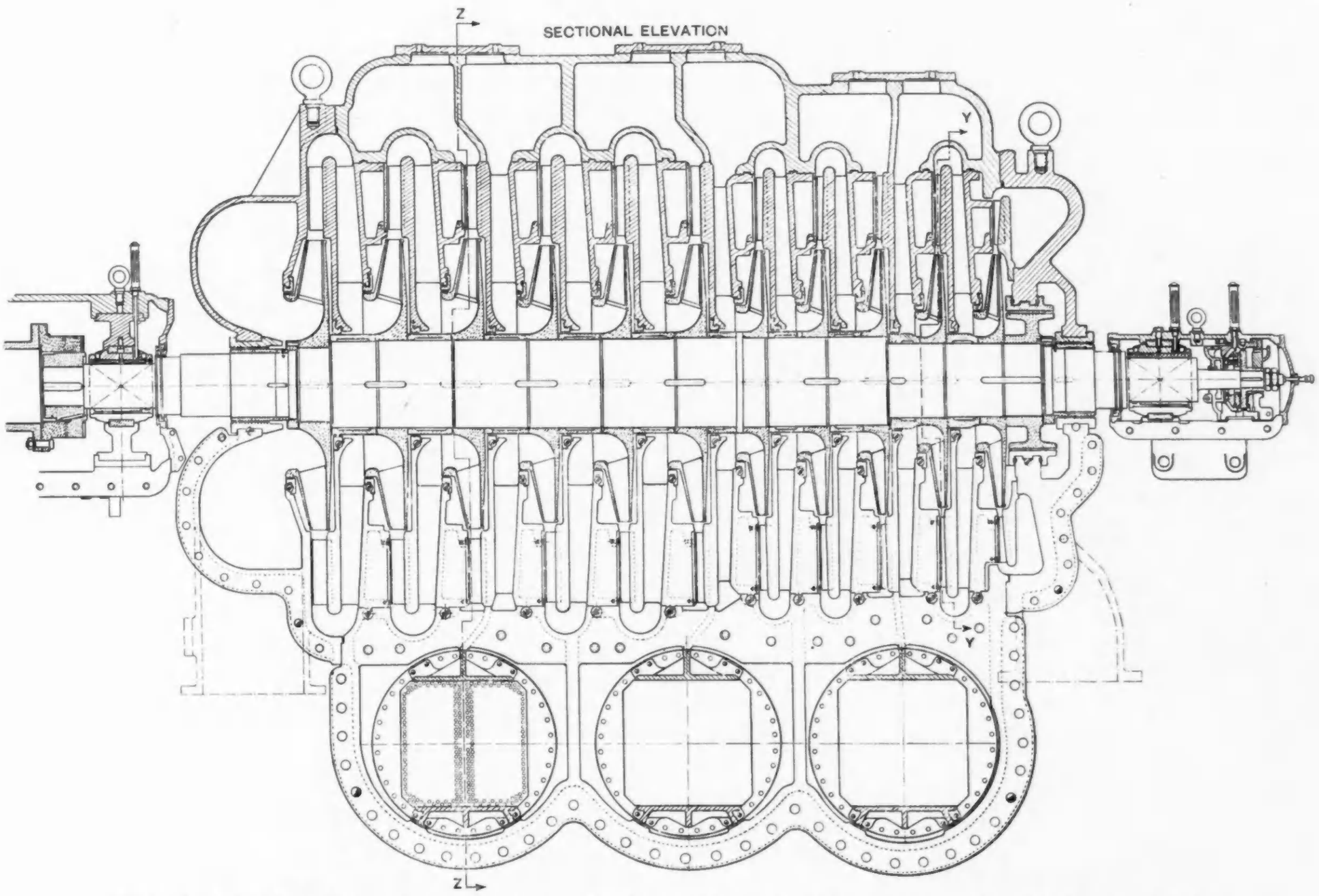


Fig. 19.—Single casing turbo-compressor with intercoolers, 36,000 cu. ft. per min., 120 lbs. per sq. in.

It is obvious that the inlet and outlet can also be made as castings.

In the case of turbo-compressors having a delivery pressure from 50 lbs./sq. in. upwards, the increased peripheral velocity had obviously the same effect on the volumetric and manometric capacity as in turbo-blowers. The special feature of a turbo compressor is the comparatively large number of stages, which has led with moderate peripheral velocity to designs of two and even more casings. An example of a two casing compressor in which the casings are water cooled and an inter cooler is inserted between the L.P. and H.P. casings, is shown in fig. 18. This machine is capable of dealing with 25,000 cu. ft. of free air (30" bar.) per minute, against a pressure of 110 lbs./sq. in. gauge.

With more up-to-date peripheral velocities the number of stages is reduced until they can all be accommodated in a single casing. Figs. 19 and 20 show such a compressor, capable of dealing with 36,000 cu. ft. of air per min., compressing it from 30" bar. to 120 lbs./sq. in. gauge. In fig. 19 the top part represents the sectional elevation (the inlet and outlet being shown in chain dotted line in the lower part) while the sectional plan at the horizontal joint is shown in the lower part of the figure. Fig. 20 gives two cross sections through the machine.

The shaft carries eleven impellers of four different diameters and a balancing piston, and is located longitudinally by a Michell thrust bearing mounted at the end of the shaft; the bulk of the longitudinal thrust on the impellers is taken up by the balancing piston. Each impeller consists of a main disc, pressed and keyed on the shaft, of a side plate, both made of high tensile alloy steel and pressed blades riveted to the main disc and side plate.

All the internal packings, the balancing piston packing and the end packings are of the labyrinth type.

The casing consists of the intake, the delivery volute and the main cylinder, all being bolted together along permanent circular joints. It has a horizontal joint with bolting along the outside wall as well as along the inner wall. The main cylinder casing is arranged for insertion of six intercoolers, three on each side. The top and bottom halves of the main cylinder are symmetrical, the coolers extending an equal amount in both halves. This arrangement ensures the shortest possible passage for the air between the diffuser outlets and the coolers, and in consequence affords a minimum resistance.

The six coolers are of identical dimensions and therefore interchangeable. The air passes through three successive stages and then through a pair of intercoolers (one on each side of the compressor casing). This occurs three times in the course of the whole compression.

The coolers consist of closed pitched tubes soldered at each end to the tube plates. Spacing plates are inserted between the tube plates to stiffen the tubes. The tube plates are bolted to the water boxes. The bottom water box is bolted to the casing, the top water box being guided by means of a stuffing box, which not only prevents air leakage but at the same time allows free expansion of the tube nests in a vertical direction. To eliminate air lock the top water boxes are provided with an air escape, fitted with an adjustable discharge, while water inlet and outlets are provided on the bottom water boxes. The water flows through the tubes in two passes in one of the coolers and then in two passes through the other, an expansion joint being inserted in the water pipe connecting the two coolers. By removing the top stuffing box, unbolting the bottom water box and removing the water pipes, the whole cooler can be lifted out by means of a crane for inspection and cleaning the outside of the tubes. The inside of the tubes can be cleaned with the cooler in position provided that the water supply is stopped by means of the isolating valves fitted on the inlet and outlet side of each pair of coolers.

The air flows in one pass across the cooler tubes, while the water supply and discharge to and from the three pairs of coolers are paralleled by means of bus pipes.

In order to separate the moisture condensed in the intercoolers, drains are provided on the lowest part of the casing after each pair of intercoolers.

In the main casing cylinder are inserted diaphragms made in halves which form the diffusers, the return channels and chambers for the impellers. The diffusers are provided with straight guide blades (clearly visible in fig. 20) which are made of steel plates cast in the diaphragms.

(*To be concluded*).

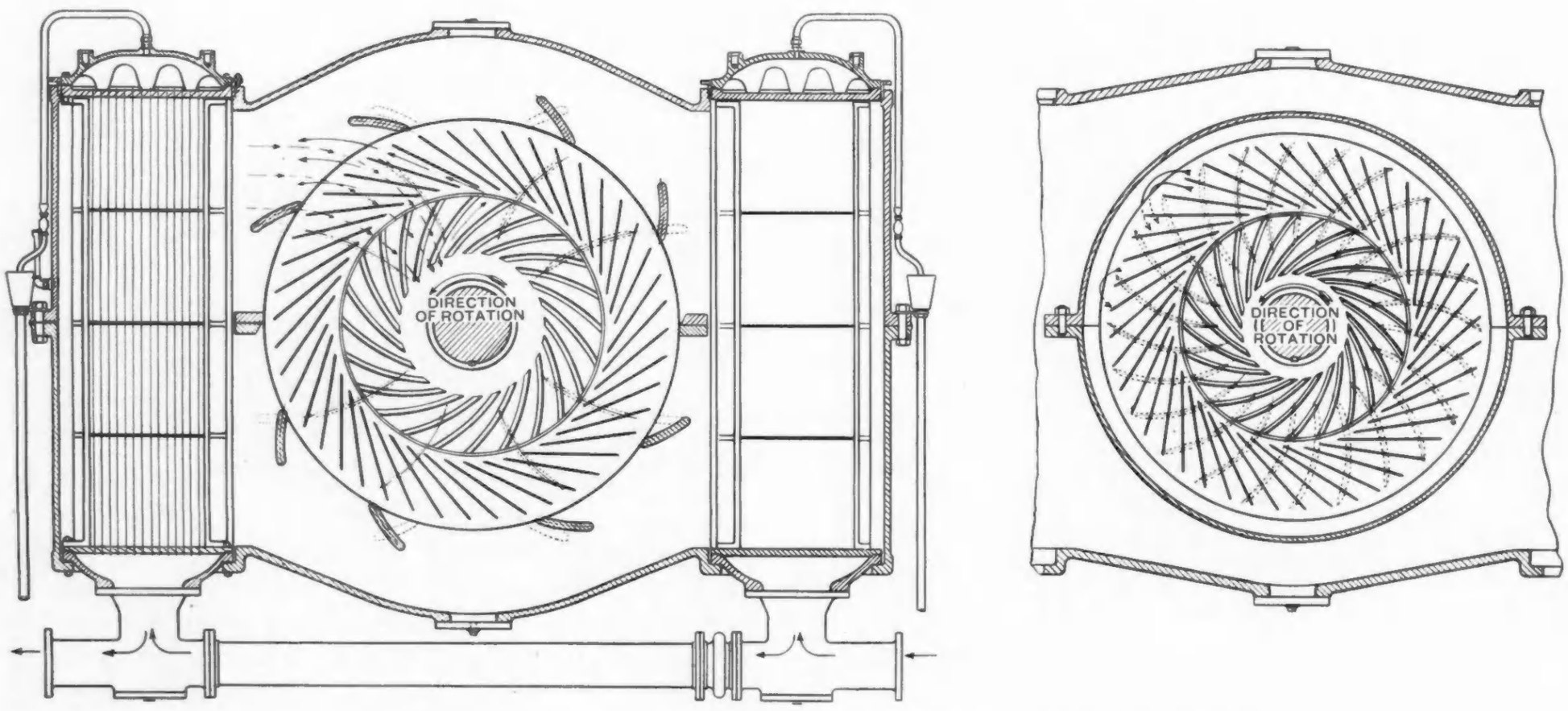


Fig. 20.—Cross section ZZ and YY of turbo-compressor shown in fig. 19.

Recent Developments in Electric Thermal Storage Cookers.

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G. R. F. SCOTSON, M.A.
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Electric thermal storage cookers formed the subject of an article which appeared in the G.E.C. Journal, Vol. III, No. 4, November, 1932. In that article the general history and principles of thermal storage cooking were discussed, and a new cooker, designed on those principles, was described. The interest displayed in that model by supply engineers in all parts of the world has shown convincingly that there is an important field for the development of such cookers, while the experience gained has enabled many advances to be made. Recent research has therefore been devoted to a more detailed analysis of cooking requirements, and to the determination of the most efficient means of meeting such requirements with a cooker of the storage type. As a result of this work, two new cookers have been evolved, and in this article the authors describe these cookers, and discuss fully the economic considerations underlying their design.

THREE POINTS OF VIEW.

THE primary object of the designer of electric cookers must be to satisfy the demands of the cook. But he must also bear in mind the interests of the electricity supplier, who is mainly concerned with the economy of supplying electricity, and of the consumer, who wants to obtain cooking service as cheaply and conveniently as possible.

Conventional electric cookers have now reached a stage of development which leaves but little to be desired in the matter of cooking performance, but to the supply engineer they represent a type of load which cannot be regarded as ideal, even though, at the present time, it may not generally be a cause for serious concern.

Storage cookers have been produced with a view to offering the electricity supplier a type of load which is intrinsically cheaper to supply than the normal cooker load, while at the same time providing cooking facilities which compare favourably with those of standard cookers.

Since load characteristics provide the basic reasons for introducing the principle of thermal storage into electric cooking, it is logical to consider first the conditions prevailing among electricity supply systems. When the requirements of these have been defined it will be shown how the needs of the cook can be fulfilled within the bounds prescribed.

GENERAL CONSIDERATION OF SUPPLY CONDITIONS.

It is now common practice to divide the cost of supplying electricity into running costs, which vary with the quantity of electricity consumed, and capital charges, which are influenced mainly by the size of generating and distributing equipment, and therefore by the maximum demand for which the system has to cater. It is clear, then, that the ideal load for economical supply is one which has a constant value throughout the twenty-four hours, for such a load makes the fullest use of the installed plant, and the capital outlay for a given output of units is a minimum. The earlier thermal storage cookers had a constant load, and, considered on their own merits, they fulfilled the ideal requirements, but a supply authority is less interested in the nature of individual loads than in their combined effect on the system. Since some types of load, by their very nature, are bound to cause a maximum demand or peak at some particular time of day, it follows that other loads, which need not be supplied during this period are preferable even to those having a constant load. Furthermore, if by any device it is possible to reduce the contribution made to peak load by an existing class of apparatus, then the monetary value of the device is equal to the saving obtained in those costs which depend upon maximum demand. If the device can be applied at a cost which is less than the value of such saving, then its adoption is economically justifiable to both supplier and consumer.

APPLICATION OF THERMAL STORAGE.

The principle of thermal storage can often be applied to electric heating apparatus to reduce its maximum load, at the expense of a slight increase in energy consumption, and this principle has been extensively applied in the case of water heating. It can be economically applied to electric cooking if the saving in maximum demand and distribution

charges is greater than the cost of extra units consumed, and it has the added advantage that by reducing the maximum load of the cooker, it enables electric cooking to be extended to localities where the supply mains are too small to carry the full load of standard electric cookers. The principle can be applied in almost any degree according to special requirements, and since these vary with the nature of the supply system, it will be necessary to analyse those features of the latter which affect the cooker load.

Fig. 1.—Semi-storage cooker.

TYPES OF SUPPLY SYSTEMS.

For present purposes electricity supply systems can be classified according to characteristics as follows :—

1. Urban systems of which the daytime load is mainly industrial, and which carry a heavy lighting load (for streets, shops, factories, etc.)
2. Urban and suburban systems where the domestic load is a major proportion of the total.
3. Rural systems where the total load is comparatively small, and where the supply has to be carried over relatively great distances to reach consumers in scattered situations.

Each one of these classes presents a different set of problems. Systems of the first type are likely to experience their heaviest load during the early evenings of the winter months, when the lighting and industrial loads overlap. Although the cooker load is not likely to be heavy at this time, it will not generally be negligible, for cooking will be taking place in preparation for evening meals, of which some will be full dinners. On such systems, therefore, the average contribution to peak load per cooker installed will be small, and the proportion of maximum demand and distribution charges which must be debited to each cooker is also small. Systems of the second type carry a load of which a major proportion is due to domestic appliances. The fluctuations in the total load will largely follow those of the domestic load, and the system peak will generally coincide with the domestic peak, which will probably occur when the cooker load reaches its maximum value. In such cases a relatively large proportion of the peak load charges will be attributable to cookers. Finally, systems of the third type will generally be supplied by mains of comparatively light section, and the maximum permissible load will be strictly limited. Standard electric cookers, with their high maximum load, would be quite out of the question, especially as the total number of cookers which could be connected would be too small to permit any substantial allowance for diversity. Without thermal storage cookers, electric cooking in such districts would not be available.

THE NEW COOKERS.

To meet the varied requirements of these different types of supply systems two new cookers have been developed. The first is best described as a semi-storage cooker, and is intended for general use where the supply mains to individual consumers are not too small to carry its maximum load of 1,950 watts. Its *average* demand is less than that of the other new model, which is an all-storage cooker, generally similar to the earlier models, and having a maximum demand of 500 watts. This latter cooker is intended for rural areas where the semi-storage cooker cannot be used for the reasons already mentioned. These cookers will be described in detail after a short discussion on cooking requirements and the application of thermal storage methods, as this procedure will give the reader a clearer idea of the reasons underlying the adoption of certain special features.

ANALYSIS OF COOKING REQUIREMENTS.

There are three main classes of operation which together constitute normal domestic cooking, and these three make essentially different demands upon the cooker. Firstly, there are the various hob operations, such as boiling, stewing and frying, all of which require a more or less *definite quantity of heat*. This can be supplied at temperatures which may vary over a wide range, so long as the lower limit exceeds the temperature of boiling water by an amount sufficient to give the appropriate rate of heat transfer from hotplate to vessel.

The second group comprises the various forms of oven cooking, all of which require a *definite temperature*, and the supply of heat must be sufficient

to maintain the desired temperature conditions. A final small group includes grilling and toasting, which require *radiant* heat at a relatively high temperature. A satisfactory cooker must be capable of performing any of these operations at any time when they may reasonably be required.

COOKING BY MEANS OF STORED HEAT.

The heat necessary for the first class of operations can be stored in any convenient medium, and at any temperature which fulfills the requirement mentioned. A number of different materials, both solid and liquid, have been tried for the storage medium, and for practical purposes, cast iron has been found best. The quantity of heat stored in a given material is proportional to the product of the mass and the temperature. In other words a small reservoir at a high temperature can hold the same store of heat as a larger reservoir at a lower temperature. Now the rate of stand-by heat loss from the reservoir is proportional to the difference between its temperature and that of the exterior of the cooker, and owing to practical limitations as to form of construction, the hob is one of the main channels of such heat loss. It follows that the temperature of the reservoir in the neighbourhood of the hob should be as low as possible, and therefore, from the foregoing, the mass must be as great as practicable. Generally speaking, however, the temperature of the reservoir under these conditions is not sufficient to give grilling, or satisfactory oven heating although it fulfills all the requirements of hob cooking, and separate provision must be made for these processes. In the two new cookers this has been done in two different ways. In the semi-storage cooker, the oven and grill have been separated entirely from the main storage block, and are heated by independent elements of their own. In the all-storage model a separate small reservoir stores heat at a temperature sufficiently high to fulfil all the requirements of grilling and oven heating. Both cookers have a large reservoir of heat for hob cooking.

SEMI-STORAGE COOKER.

This cooker is designed to cook for a household of six or seven persons. Its external appearance is shown in fig. 1, while fig. 2 shows diagrammatically the arrangement of the grill, oven, and storage block. The latter is of cast iron, and its upper surface is machined flat so as to serve as a hotplate. It is enclosed at sides and bottom in a metal canister, and supported by chains from the four upper corners of the cooker body. The object of the canister is to catch any liquids which may be spilt on the hob, thus preventing them from soaking into the lagging, and also to avoid the necessity for disturbing the latter when the block is removed for transport, etc. The block has two 250 watt heating elements which provide a maximum input of 500 watts, but, under normal conditions, only one of these is used, giving a loading of 250 watts. The block is heat-insulated from the oven, which is heated in the conventional manner, by elements situated at top and bottom. The top elements, used independently, serve as a grill. All the heating elements are under the control of a special four-position rotary switch, whose four positions give the following arrangements :—

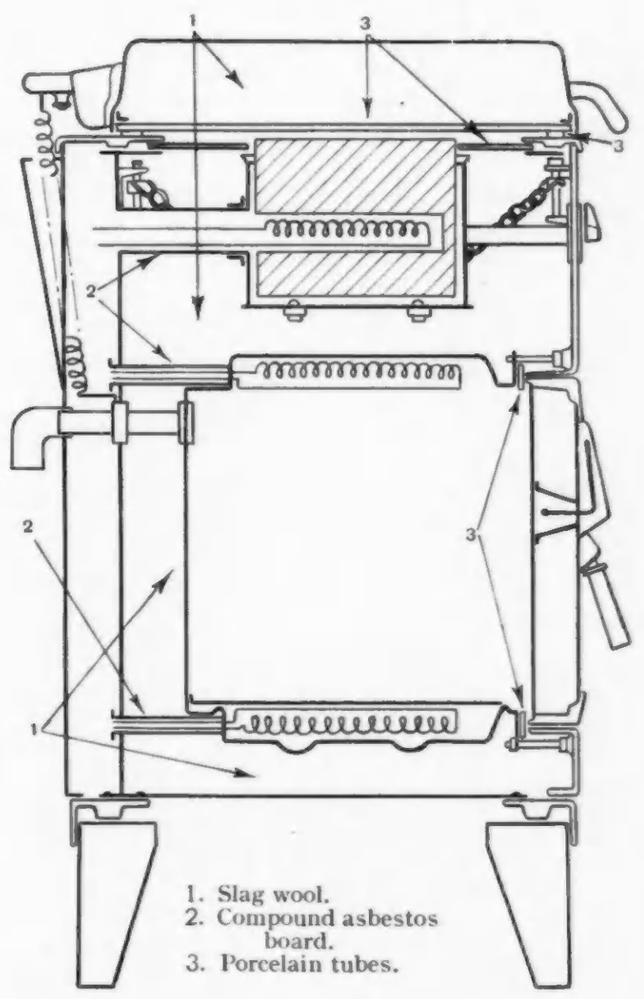

Fig. 2.—Diagrammatic section of semi-storage cooker.

Position 1. "Normal." Block heating elements only.
Position 2. "Grill." Two grill elements only. 1,500 watts.
Position 3. "Oven High." Two oven-bottom elements and one grill element. 1,950 watts.
Position 4. "Oven Low." One oven-bottom element. 600 watts.

These four positions are alternative, and as the block elements are switched off while either oven or grill is in use the maximum possible loading of the cooker is 1,950 watts. There is also a subsidiary switch controlling the block heating elements. The positions of this switch are marked "Off Duty," "Normal," and "Heavy Duty," and give loadings of 125 watts, 250 watts, and 500 watts respectively. While the "Normal" 250 watts load provides sufficient heat for all normal cooking, the "Heavy Duty" 500 watt loading enables the cooker to meet any extra heavy demands which may occasionally be made upon it. The "Off Duty" loading of 125 watts is just sufficient to keep the cooker hot during short periods of absence from home, (e.g. week-ends) so that it is ready for use immediately on return. In all usual

circumstances, therefore, both the switches on this cooker stand at "Normal," (loading 250 watts) throughout the 24 hours, except when the oven or grill is in use. The "Oven High" loading of 1,950 watts is used only to pre-heat the oven to roasting or baking temperature, at which it is subsequently maintained by the "Oven Low" loading of 600 watts. The "Grill" loading of 1,500 watts will only be in use for very short periods, as grilling and toasting are essentially rapid processes. It is evident, therefore, that the loading of this cooker will only exceed the normal 250 watts for quite short periods. Moreover, the nature of the processes which require the higher loadings is such that there will be a very high diversity in the use of the latter in any area where a number of these cookers are installed. Further reference will be made to this subject in a later section of this article. Finally, the great flexibility of control of the cooker makes it possible to switch off the block-heating elements by time-switch during any two hours or so of the day, corresponding to the period of peak load on the supply system. This means that all hotplate cooking can be done by means of an entirely off-peak load, and such processes form the bulk of all normal household cooking.

Fig. 3.—All-storage cooker.

ALL-STORAGE COOKER.

This model is the lineal successor to previous G.E.C. storage cookers. Its main constructional features and its load characteristics are very similar to those of its predecessor, but experience gained with the latter has enabled several important improvements to be made.

The cooker is illustrated in figs. 3 and 4, and it will be seen that it is externally similar to the semi-storage cooker just described. In fact the two cookers have been built, as far as possible, from parts which are interchangeable between the two models. Reference to the diagrams figs. 2 and 4 will immediately show the main points of difference between them.

The all-storage cooker has a small additional storage block, below the main block, and the purpose of this smaller block is to store the necessary quantity of heat at a sufficiently high temperature for grilling and oven-heating. This block is permanently fixed to the oven-top, and its lower surface can be exposed by the removal of a polished chromium plated reflector. Radiant heat is then available either for

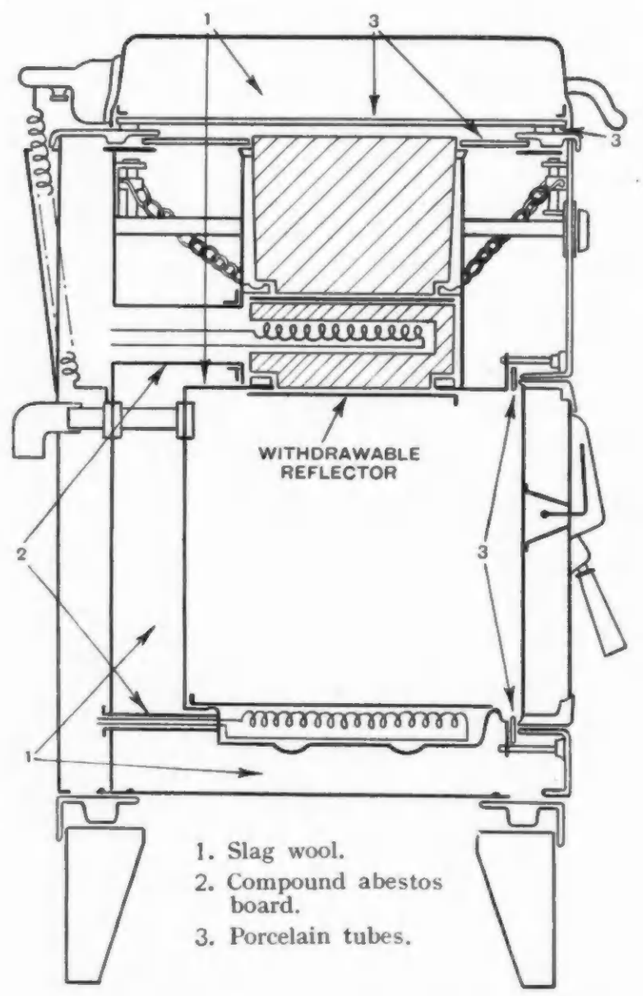

Fig. 4.—Diagrammatic section of all-storage cooker.

grilling or oven pre-heating. Two heating elements, loaded to a total of 450 watts, are situated in the lower block, and these, with the single 500 watt element in the oven-bottom, are under the control of a rotary change-over switch, so that the maximum loading of the cooker is 500 watts, while the normal is 450 watts. A sheet of polished aluminium is placed in the air gap between the lower and upper blocks, and the high thermal resistance thus formed restricts the upward heat flow to an amount sufficient to meet all normal hob-cooking requirements. The upper block of this cooker, in fact, fluctuates between the same limits of temperature as the block of the semi-storage cooker, so that the heat losses via the hob are the same in the two models. At the same time, by virtue of the thermal resistance between the upper and lower blocks, a substantial temperature difference is maintained between them, and a supply

of high-temperature heat is available for grilling, etc. Moreover, a rapid fall in the upper block temperature, brought about by heavy use, is not accompanied by a similar fall in the temperature of the lower block, so that the performance of the cooker for grilling and oven work is not materially influenced by previous use of the hob. Fig. 5 illustrates this by showing the temperature fluctuations of the two blocks during the course of a day's cooking which consisted almost entirely of hob

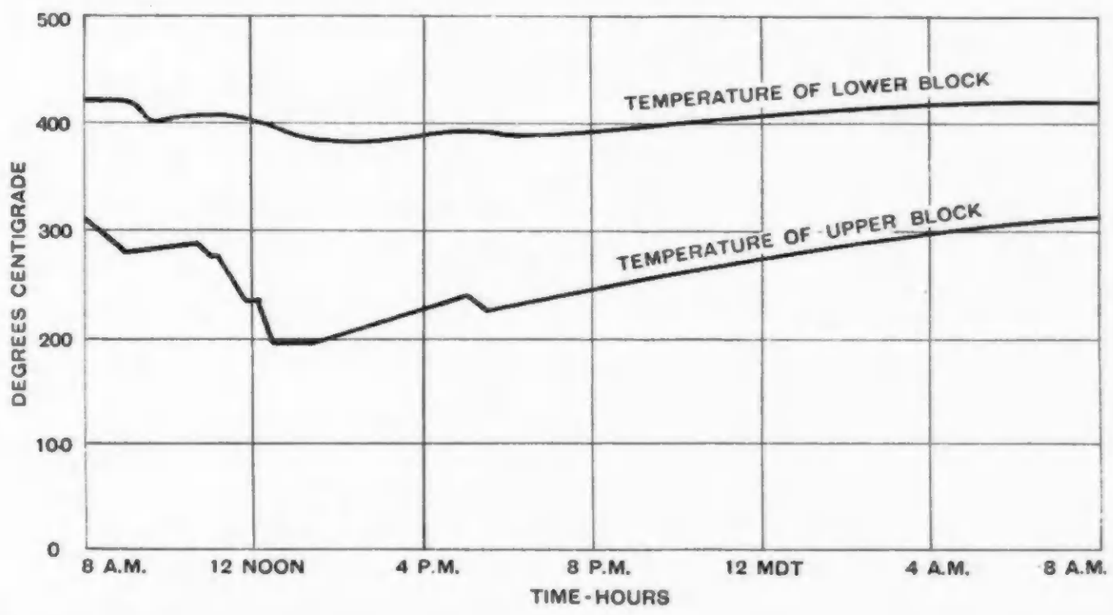

Fig. 5.—Fluctuations in the temperature of the upper and lower storage blocks of an all-storage cooker during the course of a day's cooking taking place almost entirely on the hob.

operations. The temperature of the lower block falls during the course of oven-cooking, as its heat supply is then temporarily cut off, but on account of its light weight (compared with the upper block) it rapidly regains its usual temperature when the heat supply is restored.

Under normal running conditions the oven is at a temperature of about 150°C (300°F), and is thus immediately available for processes which require only a low oven temperature. It is pre-heated to roasting and baking temperature by turning the change-over switch to "Oven," and withdrawing the reflector from beneath the lower block. Heat is thus admitted to the oven from top and bottom, and the desired temperature is reached in about 20–25 minutes.

The division of the storage block into two separate parts has solved many of the difficulties which were previously experienced with storage cookers, for while the cooking performance has been considerably improved, the average energy consumption is 10 per cent less than that of the previous model. The latter is due mainly to the reduction of the average temperature in the neighbourhood of the hob.

The cooker thus extends the main advantages of electric cooking to consumers in isolated situations, where the cost of a cable large enough to feed an ordinary cooker would be prohibitive.

PERFORMANCE OF THE NEW COOKERS.

Earlier thermal storage cookers were designed to cook for a family of six or seven, and both the new cookers are normally rated for the same number of persons. But while the older models were uneconomic for a smaller number of people, and were at the same time unable to meet heavy or prolonged overloads, the new semi-storage cooker suffers from neither of these limitations. Under certain conditions it is more economical than a standard cooker when cooking for *four* persons, while the "Heavy Duty" loading of the block-heating elements provides ample reserve to meet unusually heavy demands. For example, a reasonable amount of water for washing up can be heated on this cooker, whereas the older storage cookers, and even the new all-storage model

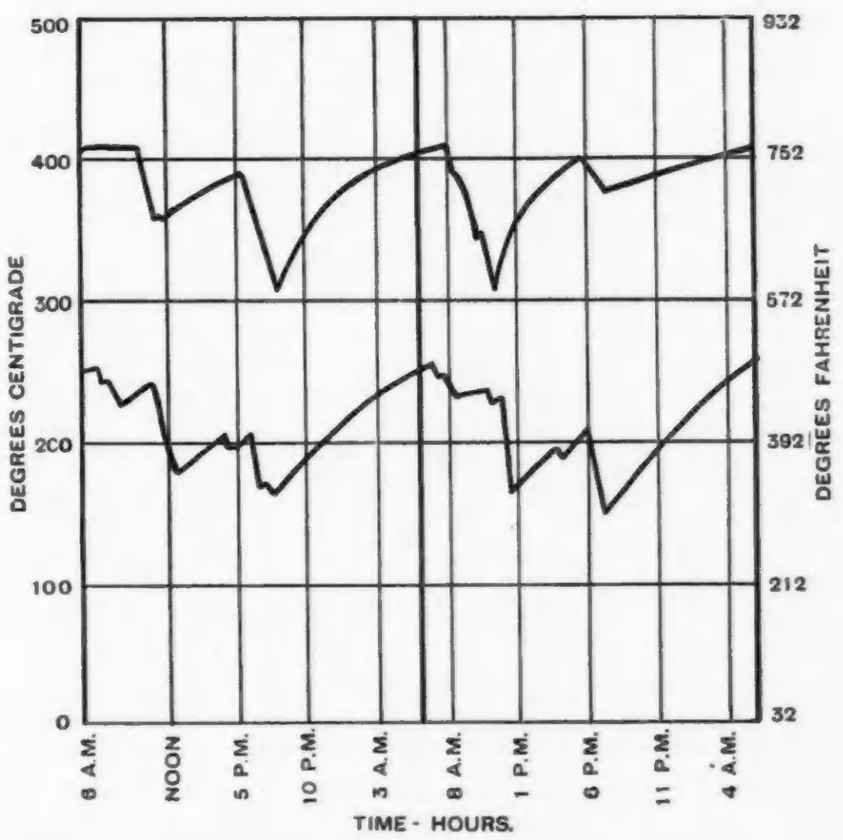

Fig. 6.—Temperature fluctuations of both storage blocks of an all-storage cooker during the course of two days' heavy cooking.

are not generally able to give this service. It might appear, at first sight, that oven cooking and grilling on the semi-storage cooker were limited only by the size of the oven, but it must be remembered that the block-heating elements are automatically switched

off when the oven or grill is in use, so that unduly heavy use of the latter might handicap subsequent cooking on the hob. For all practical purposes however, there are no serious limitations in the use of the semi-storage cooker. In the all-storage model a reduction has been made in the energy consumption, and a greater reserve of heat has been provided than was the case in the earlier model. The amount of cooking which can be carried out is of necessity more closely restricted than in the semi-storage model, but this restriction is well outside the bounds of normal use. It will only become apparent if an attempt is made to cook continuously for more than the rated number of people or to cook several meals at one time without allowing time for the reserve of heat to be replenished. Thus, fig. 6 shows the block temperature fluctuations of an all-storage cooker during the course of two days' heavy cooking. The fact that the blocks regain their temperatures at the beginning of each day shows that the cooker could continue indefinitely to meet the demand made upon it.

The two storage cookers, although they are primarily designed for the benefit of the electricity supplier, offer several important advantages to the cook. Thus, they give very rapid boiling of water (from cold), easy simmering, and simplicity of control which is not possible with the standard type of electric cooker. The oven of the all-storage cooker is normally at a temperature of about 150°C (300°F) and is immediately available for certain processes requiring a low oven-temperature, while long-period simmering can be carried out most economically by bringing the vessel to the boil on the block, and then transferring it to the oven. In this way the heat of the storage block is conserved for rapid boiling, etc., and the simmering itself is done in the ideal way—very gently.

To the electricity supplier, both cookers offer great advantages in respect of simplicity of installation, negligible maintenance costs (the block-heating elements run at a relatively low temperature, and are almost everlasting), and an economy in supply costs on account of their load characteristics. This will be discussed in detail in the next section.

The temperatures of the storage blocks fluctuate throughout the day, according to the use which is made of the cookers. Generally speaking, the maximum, of about 320°C (610°F), is reached first thing in the morning, and the minimum, of 180°C (356°F), immediately after cooking a heavy meal. As the main storage block weighs 165 lb., the heat stored between these limits of temperature is about 5000 B.Th. U. (1.45 kWh), *i.e.* enough to boil 26 pints of water. The time taken to boil water from cold depends on the temperature of the block, the range of variation being shown in fig. 7. It will be seen that the time varies from $3\frac{1}{4}$ minutes to $8\frac{1}{2}$ minutes (in a flat-bottomed kettle with $8\frac{3}{4}$ in. diameter base). The lower block of the all-storage cooker is always at a temperature well above what is required for grilling and toasting, except after heavy use of the oven, which means that these processes are possible whenever they would normally be required. Moreover, since the temperature of the lower block is hardly affected by cooking on the upper block, oven pre-heating is practically independent of any previous boiling or stewing which may have taken place. Finally the energy consumption of the new all-storage cooker is 10 per cent less than that of the earlier model. Thus several important improvements have been made over previous practice, and all of these are attributable to the two-part construction of the storage block.

Fig. 8 shows the block-temperature fluctuations of the semi-storage cooker when performing a heavy cooking schedule, (A) with the block elements switched off by time switch from 4 p.m. to 6 p.m. (hypothetical peak-load period), and (B) without such time-switch control. The figure also shows the extra use of the "Heavy Duty" block loading required to maintain the temperature.

COMPARATIVE RUNNING COSTS OF STANDARD AND THERMAL STORAGE COOKERS.

In an early part of this article it was pointed out that electricity supply costs depended partly on the quantity of electricity consumed, and partly on the maximum *rate* at which the energy had to be supplied. The influence of the standard electric cooker load on various types of supply systems was

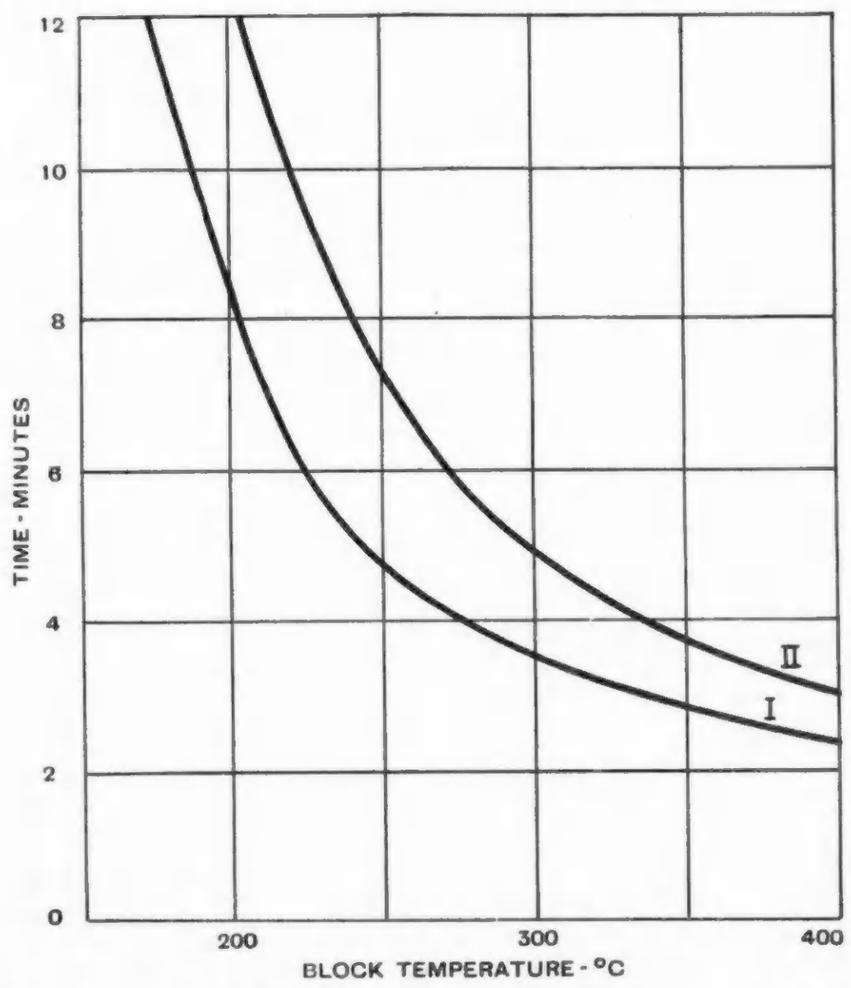

Fig. 7.—Time taken to boil 3 pints of water (from 15°C.) on a semi-storage cooker (I) in kettle with $8\frac{3}{4}$ in. dia. base and (II) in pan with 7 in. dia. base, at various initial temperatures of storage block.

also discussed, and it was explained that the aim in designing thermal storage cookers was to reduce the maximum demand and distribution costs. In most cases the reduction in these costs outweighs the cost of extra units consumed, so that a nett saving results from the use of storage instead of standard cookers. In this section it will be shown how comparative costs can be calculated for the two types of cookers under various supply conditions, and an example will be worked out on an assumed basis of allocation of the maximum demand, distribution, and management costs.

Let us consider first the load which is likely to be thrown on the supply system by a number of 6–7 person cookers of the standard type. At any given time some of these cookers will be off circuit, while the load due to any one of the remainder may be anything up to the full load of the cooker. If the total load due to the cookers at any time is divided by the number of cookers installed, the resulting figure gives the average load per cooker at the time in question, and if the time is selected to be that of system peak-load, the figure gives the average contribution to peak load per cooker installed.

If this figure is further divided by the maximum possible load of a single cooker, we obtain a figure representing the overall diversity of the cooker load at the time in question (the overall diversity is defined as the actual load due to cookers at a given time divided by the total connected cooker load).

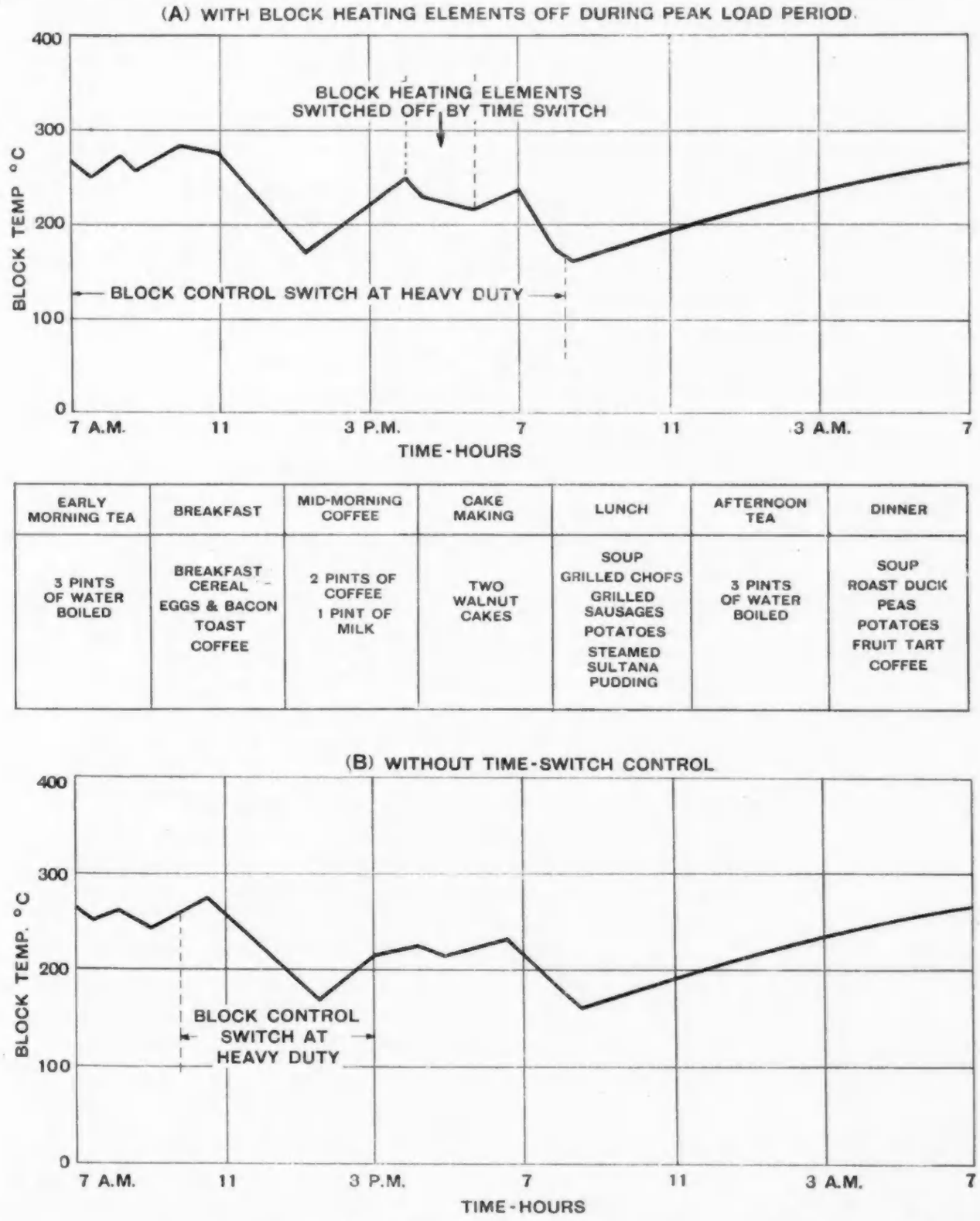

Fig. 8.—Temperature fluctuations of block in semi-storage cooker (A) with block switched off by time switch, and (B) without time switch control.

A detailed examination of the various types of meals taken, and an analysis of the cooking required for them will show that at least 50 per cent of the average load per cooker (as defined above) is due to hotplates, the remainder being due to ovens and grills. Now the storage cookers only depart from their normal loadings when the ovens (and in the case of the semi-storage cooker, the grills) are in use. If, therefore, the average load per standard cooker is known, it is possible, within fairly close limits, to

calculate the corresponding load per storage cooker *doing the same cooking*. Table 1 shows corresponding figures for storage and standard cookers, and also the overall diversities corresponding to given loads per standard cooker. (The maximum load of the standard cooker has been taken as 7.7 kW). It will be noted that the fifth column includes figures for the semi-storage cooker with its block heating elements switched off by time switch at the time in question. It has been previously mentioned that this cooker admits such treatment, and it will now be seen that very considerable reductions in the peak-load contribution result therefrom.

TABLE I.

Overall Diversity	Average Load per Standard Cooker	Average Load per All-Storage Cooker	Average Load per Semi-Storage Cooker	Average Load per Semi-Storage Cooker with Block switched off
per cent	watts	watts	watts.	watts
1.3	100	450–451	320–335	15–35
2.6	200	450–452	329–359	29–69
3.9	300	450–453	338–382	42–102
5.2	400	450–454	347–406	56–136
6.5	500	450–455	356–429	69–169
7.8	600	451–456	365–453	83–203
9.1	700	451–457	374–476	96–236
10.4	800	451–458	383–500	110–270
11.7	900	451–459	392–523	123–303
13.0	1000	451–460	401–547	137–337
14.3	1100	452–461	410–570	150–370
15.6	1200	452–462	419–594	164–404
16.9	1300	452–463	428–617	177–437

Now although it is not possible, in most practical cases, to know *exactly* what is the average contribution per cooker to system peak-load, an approximate figure is often available. From this figure and a knowledge of the actual values of the maximum demand and distribution costs, and the method of allocation of the latter, the complete comparison of supply costs can be worked out. There is, however, some difference of opinion as to the method of allocating the costs of distribution and management, and it is therefore impossible to give a worked example which would suit all cases, but for the sake of illustration, an example has been worked out on the basis described by Woodward and Carne.* It will be seen that in many cases the saving in maximum demand charge alone is sufficient to justify the extra energy consumption, and in these cases any saving in cost of distribution represents extra profit to the supplier.

The annual energy consumption of the all-storage cooker is 3,980 units, and is very little affected by the amount of cooking. The consumption of the semi-storage cooker may be from 2,380 units to 3,000 units according to the use which is made of the cooker. For the purpose of this example the figure of 2,740 units has been taken, based on an average consumption of 7.5 units per day, this figure having been obtained during the course of practical cooking tests on the cookers. The consumption of a standard electric cooker doing the same cooking would be about 6 units per day, or 2,190 units per annum. If the semi-storage cooker has its block-heating elements switched off by time-switch for a period of two hours each day (corresponding to peak load period), it *may* be necessary to use the "Heavy Duty" loading to compensate for this, and the energy consumption may be slightly increased. For this case, therefore, the annual energy consumption has been taken as 2,850 units, this figure having been found during the course of practical tests.

Table 2 shows the annual costs of supplying electricity to standard and storage cookers, based on the following figures :—

1. Cost of electricity bought from the Grid.
   (*a*) Cost per unit consumed.. 0.2d.
   (*b*) Maximum demand charge per kVA, per annum .. £3 10 0
2. Cost of distribution and management, per annum.
   (*a*) per kVA of effective demand at time of heavy load on the low voltage network £2 6 2
   (*b*) per kVA of effective

TABLE II.

Type of Cooker.	Annual cost to Supplier. Max. Dem. Charge.	Cost of Distribution.	Cost of units.	Total.	Annual Cost to Consumer.	Tariff charged to Consumer.	Annual Profit to Supplier.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	pence per unit.	£ s. d.
Standard 6–7 person consuming 2190 units p.a.	2 2 8	2 11 1	1 16 6	6 10 3	6 17 1	0.750	0 6 10
Semi-storage, consuming 2740 units p.a.	1 8 8	1 6 11	2 5 8	5 1 3	6 17 1	0.600	1 15 10
Semi-storage, time-switch controlled, consuming 2850 units p.a.	0 9 10	1 3 2	2 7 6	4 0 6	6 17 1	0.576	2 16 7
All-storage, consuming 3980 p.a. ..	1 11 11	1 7 6	3 6 4	6 5 9	6 17 1	0.413	0 11 4
Standard 4 person, consuming 1460 units p.a.	1 11 6	1 17 8	1 4 4	4 13 6	4 11 3	0.750	0 2 3 **loss.**
Semi-storage, Time-switch controlled, Cooking for **4 persons,** consuming 2850 units p.a.	0 9 10	1 3 2	2 7 6	4 0 6	4 11 3	0.384	0 10 9 **profit.**

* I.E.E. Journal Dec., 1932.

demand at time of heavy load on the High Voltage System £0 13 10

The overall diversity of the cooker load at the time of peak-load on the high voltage system has been taken as 8 per cent (12½ to 1) and the overall diversity at the time of peak-load on the low-voltage network has been taken as 12 per cent (8⅓ to 1). The tariff to be charged to the consumer has been so calculated that the *consumer's* annual costs for running storage or standard cookers are equal, and the resulting profits to the supplier are shown in the final column.

The two lowest rows of the table show the economy of using a time-switch controlled semi-storage cooker to cook for *four* persons. It will be seen that the standard cooker shows an annual *loss* of 2s. 3d., when the consumer's tariff is ¾d. per unit, while the time-switch controlled semi-storage cooker shows a *profit* of 10s. 9d. when the consumer's tariff is 0.384d. per unit.

It has been assumed that the peak loads on the high and low voltage networks do *not* coincide, and the time-switch control of the semi-storage cooker applies only to the *high*-voltage peak. In some cases greater savings may be effected by switching off during the low-voltage peak, though this is not so with the present set of figures.

In conclusion, the authors wish to make it quite clear that the figures in Table 2 cannot be regarded as generally applicable to all cases. Their purpose is to indicate the *method* of calculation when the relevant conditions are known, and these will vary widely from one supply system to another. The time-switch controlled semi-storage cooker, when cooking for six persons will almost invariably show an advantage over standard cookers, for it provides all hot plate cooking by means of an entirely off-peak load, while its oven and grill loadings are individually smaller than those of the standard cooker. Thus, *whatever* the peak-load contribution of the standard cooker may be, that of the time-switch controlled semi-storage cooker is necessarily less when doing the same cooking.

Electric Galley Equipment in the S.S. "Strathmore."

One side of the 14-oven island range (total loading 296 kW) installed in main galley of S.S. "Strathmore."

Electric Winder for the Champion Reef Gold Mines of India.

By C. E. CUTTING,
Manager, Madras Branch of
The General Electric Co. (India) Ltd.,
and
J. MEEK,
G.E.C. Resident Engineer, Madras.

Fig. 1 (above).—Part of the winding equipment arriving at Champion Reef Gold Mine, South India.

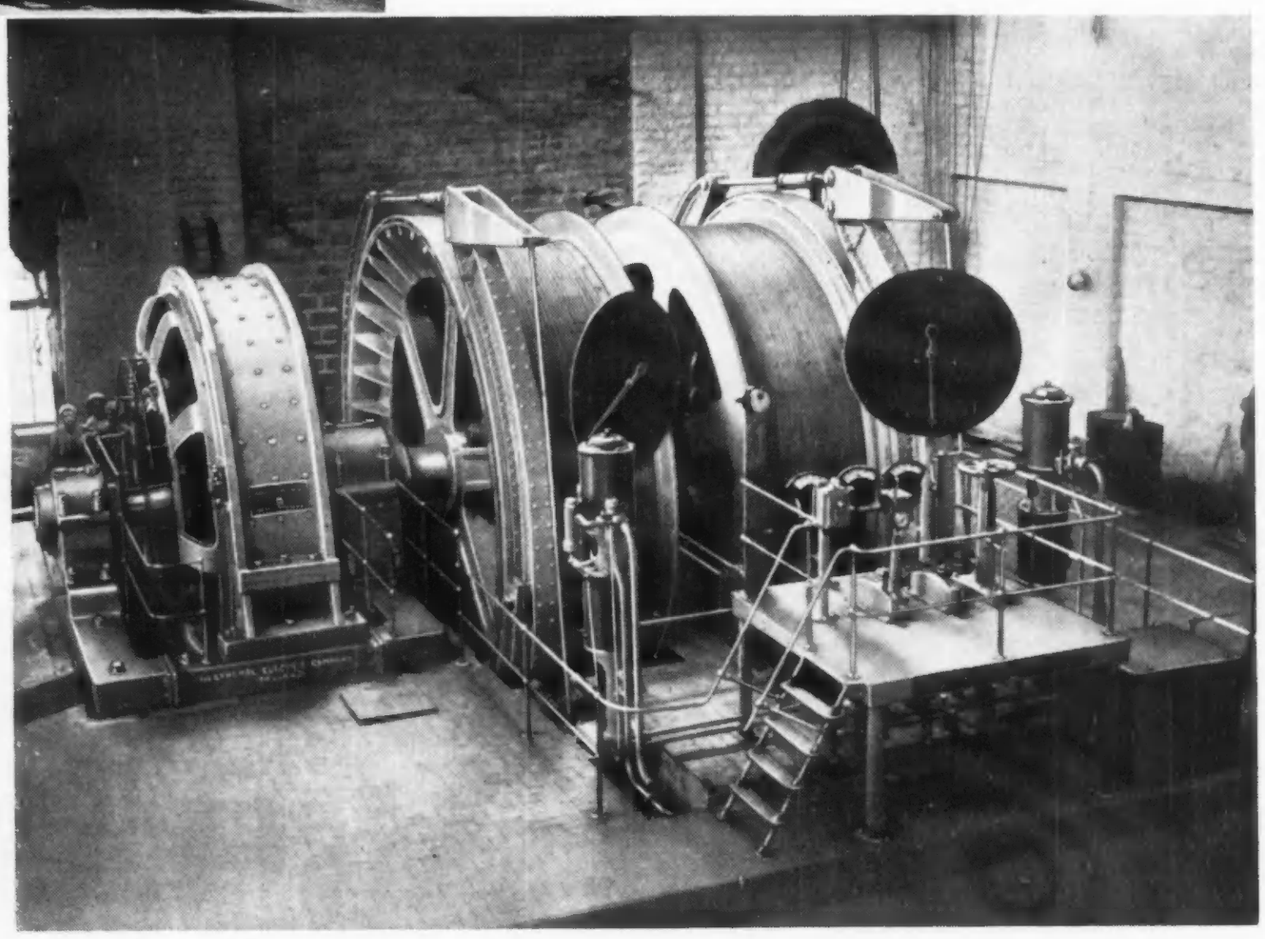

Fig. 2 (right).—G.E.C.—Fraser & Chalmers electric winder at the Champion Reef Gold Mine. On the left is the 1,150 h.p., 525 volt, 37.5 r.p.m. motor driving the winding drums.

DEVELOPMENT work in the gold mining industry has been rapidly accelerated by the high price of gold recorded for the last few years in the markets of the world. In many gold mines it has been found highly profitable to re-treat old tailings and to mine a much larger proportion of low grade ore, while opportunity has also been taken to replace obsolete and inefficient plant. This is well illustrated by the Champion Reef Gold Mines of India Ltd., which is situated in the Kolar district of the Indian state of Mysore, the site of the principal goldfield of India.

One part of the many developments and extensions which have recently been made in the Champion Reef Mine consists of the replacement of a large steam winder at the Gifford shaft by a new electric winder. The new winder and its control equipment are fully described in this article.

DISCOVERY OF KOLAR GOLDFIELDS.

It is of interest to mention that the beginning of modern mining in the Kolar district, which dates from about 1880, was due to the discovery of ancient workings. The Ancients apparently prospected about on the surface outcrops until they came upon a vein of rich ore. This they would work out with their crude appliances to a depth of 150 or 200 ft. The method employed was to heat the ore and then throw cold water on it, thereby rendering it friable and suitable for extracting the gold by hammering with pieces of hard rock. Equally primitive must have been the method used for getting rid of the flow of water which would be encountered at any depth. Large gangs of workers must have been continually employed to bale out the water with vessels which were passed up to the surface.

As regards the geology of the goldfield, the formation in which the reefs are found is a bed of schistose rock about 15 miles long. Of these reefs the main, or "Champion" lode as it is called, is the most important, and is the reef on which the richest mines are now situated.

NEW EQUIPMENT.

The equipment supplied to the Champion Reef Mine comprises an electrically operated ore hoist capable of hoisting a load of 5,300 lbs. of ore from a vertical depth of 3,633 ft. with a rope speed of 1,910 ft. per minute. For this purpose a Ward-Leonard controlled D.C. motor of 1,150 h.p. direct coupled to double cylindrical drums, together with the necessary control gear, have been installed. The whole of this winding equipment was supplied by The General Electric Co., Ltd.

Part of the equipment arriving at site is shown in fig. 1. It is interesting to note that special railway trucks had to be brought to Madras to transport the equipment to Champion Reef Station, a distance of 180 miles.

As the diameter of the armature of the winding motor is approximately 11 feet, it had to be packed on its sides for transport by rail in order to clear bridges; also, the shaft of the armature had to be withdrawn in order to bring the case containing the armature within the loading limits of the railway. The transport from Champion Reef Station to site was by means of bullock drawn vehicles as illustrated in fig. 1.

OPERATING DATA.

The working conditions of the winder, which is illustrated in figs. 2 and 3, are as follows:—

Vertical depth of shaft ..	3,633 ft.
Weight of ore lifted per wind	5,300 lbs.
Weight of cage and chains	9,212 lbs.
Weight of trucks (2) ..	1,736 lbs.
Time of actual winding ..	130 secs.
Time of decking	40 secs.
Rope speed	1,910 ft. per min.
Speed of motor and drum	37.5 r.p.m.
Diameter of drums ..	16 ft.
Width of drums between cheeks	4 ft. 6 ins.

MECHANICAL EQUIPMENT.

The two drums are of the cylindrical type, one being loose on the shaft and driven by means of a clutch, and the other keyed to the shaft. The drum cheeks are of semi-steel, and are made in halves with planed joints fastened together by fitted bolts in the hub and rim. The shells are of mild steel plate, also made in halves and bolted together, and machined where they are bolted to the drum cheeks on either side. The shells are designed with sufficient thickness to take three layers of rope, and are reinforced internally by mild steel "tee" rings.

Replaceable mild steel brake paths are provided, bolted to flanges cast solid with the outer drum cheeks, a ventilation system being embodied which prevents the drum overheating during braking. The brakes themselves are of the curved, suspended post type, each controlled by a separate brake engine. Wood block linings are fitted, and are capable of adjustment for wear. The brake engines are provided with cataract cylinders to ensure smooth braking by eliminating shocks, and the control gear is so designed that any braking force between zero and maximum can be applied. Compressed air is used to operate the brakes.

The clutch on the loose drum is of the cast steel multiple tooth type, the outer ring being fitted to the drum and the moveable portion sliding on a machined hexagon forged on the drumshaft. The clutch is operated by screw-down gear on the driver's control platform (fig. 2).

The control gear mounted on this platform comprises a control lever, a clutch lever, a brake lever and an emergency switch..

The brake lever operates both brakes in normal balanced working, and an interlock lever is fitted to ensure that the loose drum brake is fully applied before the clutch can be disengaged.

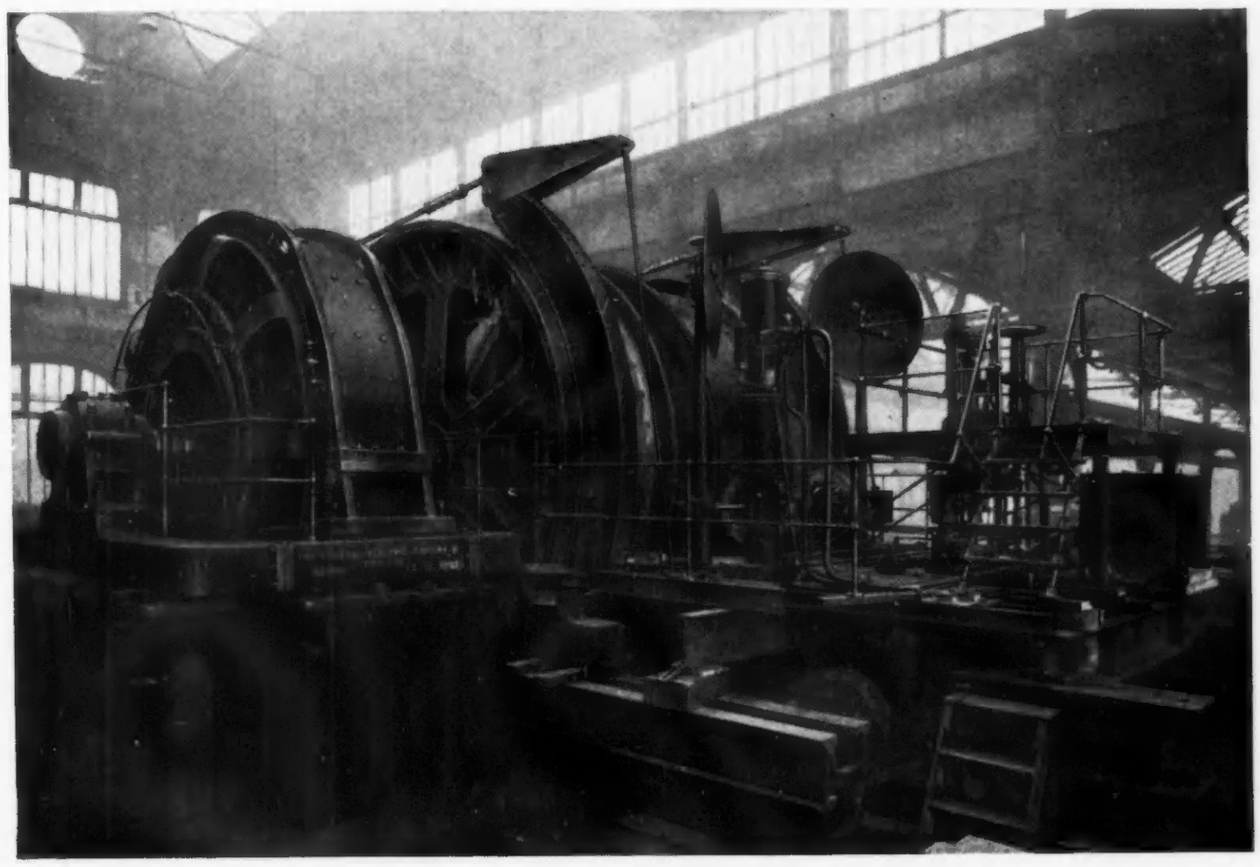

Fig. 3.—The complete winding equipment on test at Fraser & Chalmers Engineering Works.

ELECTRICAL EQUIPMENT.

The electrical equipment consists of the winding motor itself, which

is rated at 1,150 h.p. at 525 volts ± 37.5 r.p.m., an 800 kW Ilgner Ward-Leonard motor-generator set, 750/630 r.p.m. (fig. 4) and the electrical control equipment. The latter comprises :—

(1) Two truck cubicles, fig. 5, housing two truck-type oil switches with overload and no-volt protection, together with the necessary transformers supplying voltmeter and ammeter. No. 1 truck handles the main supply to the Ilgner set, while No. 2 is a "plugging" switch arranged to stop the set by reversing the stator of the induction motor relative to the line. The two trucks are interlocked as described below. An adjacent compartment contains a transformer which supplies the low-tension auxiliaries.

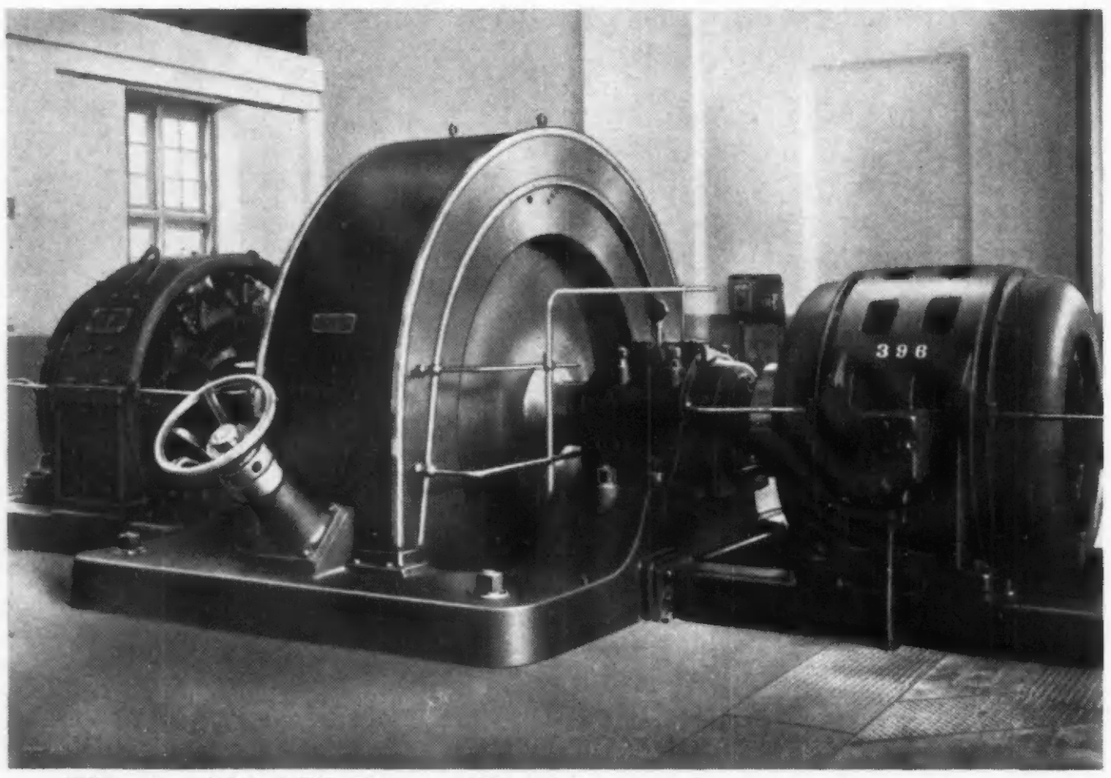

Fig. 4.—800 kW Ilgner Ward-Leonard motor generator set controlling winder motor.

(2) A combined liquid starter and slip-regulator, fig. 5, electrically interlocked with (1) to prevent incorrect operation. The liquid controller is designed to enable any of the cooling tubes to be replaced with the minimum of delay. The banks of cooling tubes are mounted in detachable headers which are carried on a separate platform fixed to the inside of the liquid controller tank. A complete header can thus be removed and replaced quickly by a spare header.

(3) A steel plate cubicle containing most of the apparatus for the control of the main D.C. generator and exciter, and of the main winder motor, namely, exciter voltmeter, ammeter and field regulator, main excitation contactor, generator field suicide contactor, together with the main motor field, weakening and protective relays, and the emergency brake solenoid contactor.

(4) Driver's Ward-Leonard controller, arranged beneath the driver's platform, and actuated by the control hand lever. In addition to the generator field regulator and electrical interlocking contacts, the controller embodied two hand-closed "back-out" switches, which enable the driver to back out of an overwind.

Also mounted near the driver's platform is an instrument pillar carrying main motor voltmeter and ammeter. Bell alarms at the platform warn the driver in the event of failure of the flywheel bearing lubrication or cooling water, and an emergency push button enables the winder motor to be stopped in the minimum safe time by automatic action of the main brakes through the medium of a brake solenoid.

SEQUENCE OF OPERATIONS.

The functions of this equipment will be appreciated by a study of the complete sequence of operations, starting with the flywheel motor-generator set at rest.

In this condition, the exciter and main motor fields are short circuited, the excitation contactor open, the exciter armature circuit closed on a resistance and the generator field "suicided." *i.e.*, connected, reversed, across its own armature. The emergency brake contactor is open and the emergency brake solenoid de-energised.

The first operation is to start the motor-generator set by closing the main oil breaker and gradually cutting out the liquid starter. The breaker, however, can only be closed provided :—

(1) The liquid starter is in the "all resistance in" position.
(2) The bearing cooling water pump motor is running.
(3) The "plugging" breaker on No. 2 truck is open.
(4) A.C. supply is available to release the handle of the main breaker (which is otherwise locked down) and to energise the no-volt coil.

The switch being closed, the set may be brought up to speed by operating the starter, and depressing the push button of the "resetting switch" on the driver's platform. This removes the short-circuit from the exciter and allows it to build up its voltage. The voltage at once picks up the main excitation contactor and emergency brake contactors, setting the brake control gear for hand control provided :—

(a) Driver's emergency push switch in the running position.
(b) Overwind limit switches closed, both on Lilly controller and track.
(c) Overspeed switches closed on both main winder and motor-generator set.
(d) Main motor overload relay set.
(e) Main motor field failure relay set.
(f) Hand brake lever in "on" position and main controller "off."
(g) Air pressure failure switch closed.

The driver now releases the controller hand lever by grasping the grip catch on the handle. This closes the field weakening contactor and applies full field to the winder motor. (This contactor is arranged to "fail to safety," *i.e.*, to give full field on failure and so avoid the possibility of weak field while a wind is in progress.) The driver may now move the controller hand lever in the desired direction, at the same time releasing the brakes. The initial motion of the controller hand lever causes the generator field "suicide" contactor to change over and connect the generator field to the exciter, in series with the whole of the controller resistance.

The generator voltage thus builds up and causes the winder motor to rotate; further motion of the handlever enables full speed to be obtained. During this portion of the wind the power demand is heavy, as the moving and rotating masses have to be accelerated. The automatic slip-regulator accordingly moves to introduce resistance and so allows the set to slow down and the flywheel to give up some of its energy. At maximum speed, the power demand falls and the slip regulator begins to accelerate the flywheel.

On approach to the bank, the driver moves his controller hand lever towards the off position, reducing the generator excitation and voltage. The motor is thus caused to feed back current into the generator, so that the latter works as a motor and accelerates the flywheel. Thus a large proportion of the kinetic energy of the winder is returned to the flywheel, and the peak power demands during acceleration are largely prevented from reaching the incoming A.C. system.

Fig. 5.—Control gear for winder; on the left is a combined liquid starter and slip regulator; on the right are the A.C. truck cubicles.

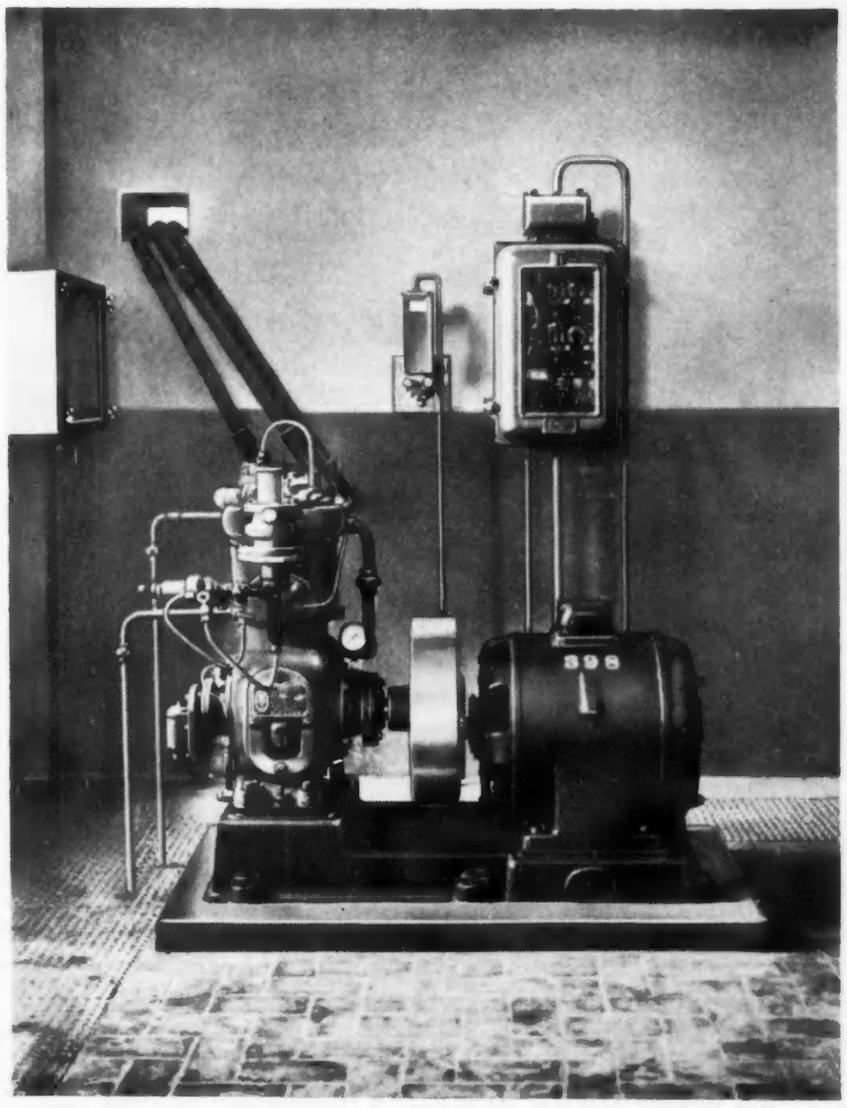

Fig. 6.—Emergency compressor plant.

As the control hand lever reaches the stop position, the motor field is weakened and the generator field contactor changes back to the "suicide" position, in which the field is connected, reversed, to its own armature. When thus connected, any voltage remaining at the generator terminals will cause a self-destroying current to circulate in the field. In this way, creeping of the winder, due to residual generator voltage, is entirely eliminated.

PROTECTIVE GEAR.

As is usual, the protective arrangements are concentrated in a single safety circuit, interruption of which will open the excitation contactor and emergency brake contactor.

The opening of the excitation contactor short-circuits the exciter field, connects the exciter armature to a low resistance, short-circuits the winder motor field and applies the emergency brake. The consequent fall in the excitation voltage will cause the generator field contactor to change over to the "suicide" position. The winder is thus brought quickly to rest. The safety circuit is arranged so that it is interrupted by:—

1. Failure of D.C. motor field.
2. Failure of exciter voltage.
3. Overload on winding motor or motor generator set.
4. Overspeed of motor generator set.

5. Overspeed of winding motor.
6. Opening of emergency push button switch.
7. Failure of power supply.
8. Failure of air pressure.
9. Overwinding of cage.

Starting up after a shut down because of one of these faults can only be made by remedying the defect and then repeating the starting sequence, omitting, of course, the starting up of the motor generator set.

In the case of an overwind, the excitation contactor cannot be reclosed unless the limit switch in the safety circuit is temporarily short-circuited. Two bye-pass switches are provided for this purpose and are built into the main Ward-Leonard controller. After an overwind, both are closed, and the excitation contactor reset. If the driver now attempts to run the wrong way, *i.e.*, to overwind further—a cam on the controller spindle opens the appropriate bye-pass switch and trips the safety circuit again. If, however, he backs out of the overwind correctly, the limit switch automatically resets itself, and at the beginning of the next wind in the same direction the cam opens the bye-pass switch and so restores the original condition. On the A.C. side the main oil circuit breaker will open on sustained overload or on voltage failure, and re-starting must then be carried out from the beginning.

An emergency motor driven air compressor (fig. 6) is provided for the brake engines, and has a capacity of 50 cubic feet of free air per minute to 60 lbs. per sq. in., and is complete with an automatic pressure regulating device to operate at 35 lbs. per sq. in.

SAVING IN HOISTING COSTS.

It may be stated that although the electric winder described in this article has only been in commission for a comparatively short time, substantial savings in hoisting costs have already been shown. In this connection it is interesting to quote the statement made by Mr. Sidney E. Taylor, of John Taylor and Sons, Managers of the Champion Reef Gold Mines of India, Ltd., in his address at the ordinary general meeting of the company, held on Friday, April 12, 1935 :—

"The new electric winding engine at Gifford shaft was brought into commission in August, and in consequence a substantial saving is being realised in hoisting costs as compared with the steam winding engine which it has replaced. The saving is at the rate of £8,000 a year, a satisfactory figure compared with the all-in cost of the new electric winder, which was just under £28,000."

CONCLUSION.

In conclusion, it should be noted that the whole installation was designed and carried out in accordance with specifications prepared by A. H. P. Fitz-Patrick, Esq., Chief Engineer of the company, in collaboration with G. W. Richardson, Esq., M.I.E.E., M.I.Mech.E., Chief Electrical Engineer of the Kolar Gold Fields Electricity Department.

"Osira" Lighting on the Albert Embankment, London.

Albert Embankment, London, illuminated by "Osira" lamps housed in the existing Dolphin standards, which were adapted to accommodate special fittings for the lamps. A total of sixty-six 250-watt lamps are installed, spaced at 20 yard intervals.

The Use of High Pressure Mercury Discharge Lamps in Industrial Lighting

By R. O. ACKERLEY,

Illuminating Engineering Dept., of The General Electric Co., Ltd.

The nature of the light emitted by the "Osira" high pressure mercury electric discharge lamp, the electrical characteristics of the lamp, and the problems involved in the design of fittings for the purpose of employing this form of light in industrial installations have been covered by articles in the G.E.C. Journal, Vol. 4, No. 1, page 46; Vol. 4, No. 4, page 199; and Vol. 6, No. 3, page 127. The present article deals with the actual application of "Osira" light in industry and discusses its advantages and limitations as a practical illuminant in comparison with electric incandescent lamps.

WHEN the "Osira" high pressure mercury lamp was first put on the market, public attention was directed far more to its possibilities for street lighting than to other potential applications. It was felt that certain characteristics of the light, which caused no disability at the low levels of illumination normally used for street lighting of even the highest standard, might prove a bar to its successful employment in interior industrial lighting where far higher intensities would be required. For this reason it was desirable to proceed with caution until practical experiment had proved or disproved its suitability.

What exactly these characteristics are which it was feared might give trouble, will be examined in more detail later in this article. Suffice it to say here that early experiments quickly showed that not only was there no reason for regarding the light as unsuitable for industry, but that some of the very features regarded as disturbing were proving definitely advantageous. Encouraged by these early results more and more industries were successfully approached and experience has shown that in the majority of cases, the resultant lighting approaches the ideal illuminant for general lighting in industry.

INDUSTRIAL LIGHTING REQUIREMENTS.

The apparent advantages of this lighting for industrial purposes may be clearly stated, but as a preliminary to considering these apparent advantages it may be of interest to examine the lighting requirements of industry, to see how far the old forms of lighting met these requirements, and to study the essential differences between this new lighting and the older forms of illumination.

Fig. 1.—Marking steel plates in a steelworks illuminated by "Osira" high pressure mercury discharge lamps. This form of lighting simplifies any operation involving the marking, or distinguishing of marks, on metal.

Briefly the requirements of industry can be summed up in the words "good visibility at the lowest possible cost," but what constitutes good visibility takes longer to describe. Stated broadly, it means light of adequate intensity falling on the work at all requisite angles from horizontal to vertical, producing sufficiently even illumination to avoid the necessity of contraction and expansion of the pupil of the human eye as vision travels from one part of the workshop to another. It must also be glareless and of such a quality as to give the clearest possible definition on all objects. These conditions are obtained in practice by control of:

(*a*) Intensity.

(*b*) Light distribution as regards (1) Direction
(2) Diffusion

in conjunction with the natural quality of light.

Fig. 2.—"Osira" lighting is particularly suitable for the illumination of foundries.

The term "quality" includes any characteristic of the light source which might advantageously or otherwise affect the power of the human eye to see objects of one nature or another when illuminated by it. The most familiar way in which light quality has been controlled in the past has been by varying its colour by means of absorbent media, but when the character of "Osira" light is examined it will be seen there are other respects in which it is different as regards the reactions it evokes from the human eye.

How far the light sources previously available have lent themselves to these requirements may now be examined. In practice the examination can be confined to incandescent electric lighting because its high efficiency and simplicity of control both optically and mechanically have made it the almost universal light source wherever "lowest possible cost" is a qualification to the demand for "good visibility."

Modern electric incandescent lighting allows considerable latitude as regards intensity in suitably graded units: it allows of good control of light distribution and its quality is that associated with any light emanating from an incandescent source in that the radiation is continuous over all wave lengths in the visible part of the spectrum.

In the case of "Osira" light, it has been shown in previous articles in the *G.E.C. Journal* that, as regards cost, the lamp is from $2\frac{1}{2}$ to 3 times as efficient as a tungsten lamp of a corresponding wattage. At this stage, the question of cost need not be considered further, but typical comparisons will be given later indicating the economic advantages of this form of lighting.

As regards intensity, the fact that in the early stages only the very powerful 400 watt "Osira" lamp was available, limited the field to some extent, as such a lamp could only be employed where adequate headroom existed. The advent of the 250 watt lamp however greatly improved this position so that to-day there are relatively few modern factories where insufficient headroom exists for this form of lighting.

As regards light distribution, it was shown in the *G.E.C. Journal* (Vol. VI. No. 3) that satisfactory reflectors have been designed to give a distribution

Fig. 3.—The deepest sand moulds can be inspected more easily with this method of lighting than with any other form of illumination.

of light similar to those most commonly called for in incandescent lamp systems and of a type generally agreed to be most suitable for industry, but it also indicated that the lamp, due to the shape of the light source, lent itself to wider spacing than the corresponding incandescent lamp without sacrificing cut-off or evenness of illumination. This potential wider spacing is clearly an advantage from the economic point of view in that for a given available mounting height reflectors may be spaced further apart and therefore a smaller number would be required; but it is more than probable that, provided evenness of illumination is not sacrificed, wider spacing offers a definite advantage from the lighting point of view in that it means higher intensity on the vertical plane, *i.e.*, on the side of the work. The importance of illumination on the vertical plane seems to have been overlooked. This is due to two main causes: first, wide distribution cannot be obtained with electric incandescent lamps and vitreous enamel reflectors without some disability in other directions; secondly, the custom which has grown of appraising lighting installations by reference to the foot candle illumination on a horizontal working plane. A moment's reflection will show that in many of the processes of industry the operative is looking at the side of his work rather than at the top, and recent experiments in the textile industry for instance, have emphasised still further the importance of this light component on to the vertical plane. From this point of view therefore "Osira" lamps may be considered to have advantages over electric incandescent lamps.

Fig. 4.—Another example of a foundry illuminated by high pressure mercury discharge lamps.

Fig. 5.—Mercury discharge lamp lighting in an automatic machine shop.

THE QUALITY OF "OSIRA" LIGHT.

Lastly, the question of light quality must be considered. The spectral difference between light from electric discharge lamps and that from incandescent lamps has also been previously referred to in this Journal.* Briefly, while the light from incandescent lamps is radiated over the whole visible portion of the spectrum, that from the new lamps is limited to certain specified wave lengths. This gives it a blue-green appearance and certain other characteristics when considered in relation to its reactions on the human eye.

Consider first the blue-green appearance, which is due to the almost complete absence of any red rays and the presence of strong green, yellow and blue components. The colour of incandescent light has been accepted as good for industry as a whole, rather through lack of any evidence to the contrary than from any definite evidence in favour. Alteration in colour of incandescent light means extra capital cost and loss of efficiency and therefore industrialists have accepted the

* G.E.C. Journal, Vol. IV., No. 1, p. 46.

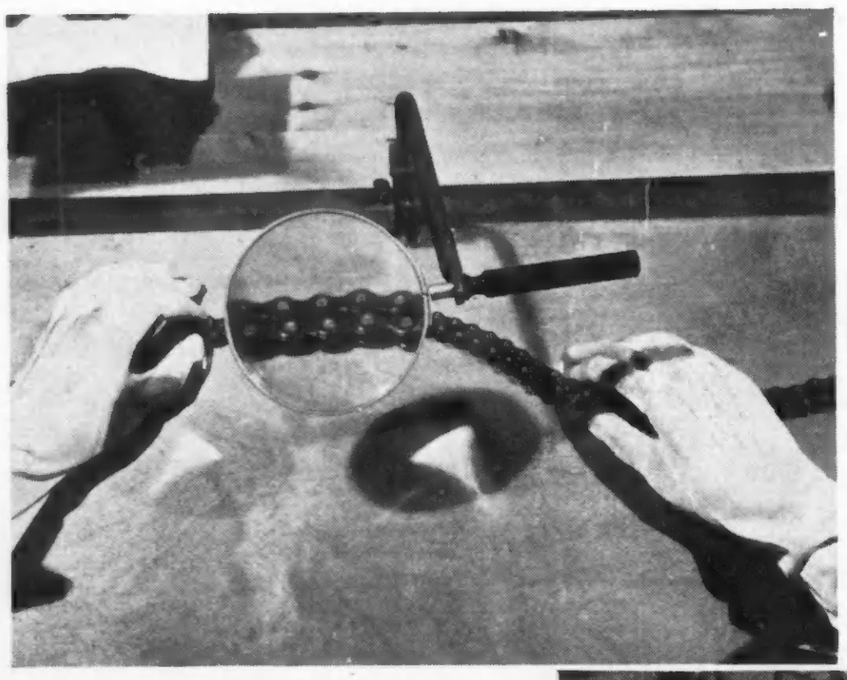

Fig. 6.—In the inspection of finished material, any imperfection is emphasised.

light as it stood except where special conditions made it essential that light of a different colour should be used. There were, however, quite sufficient instances where colour alteration was essential, with the result that there has always been a demand, even at the higher cost, for the so-called daylight blue lamps, blue glass diffusing screens and low pressure mercury lighting, forms of lighting which did not purport to give an actual daylight effect, but did definitely increase the proportion of light at the blue end of the spectrum as compared with that at the red. There is every reason to suppose that many more industrialists might have preferred a bluish light if they could have obtained it without extra cost, and the success of high pressure mercury lighting seems to indicate that such was the case. What exactly is the secret of the advantage of the blue green light from a visual point of view is still a little obscure but it may lie partly in the capacity of objects to reflect light of their own colour best. By reflecting light is meant that power of diffuse reflection which makes objects visible to us and not any form of specular or mirror reflection.

How far this explains the phenomenon it is hard to say, but there seems no doubt that the blue green light is an advantage in the great majority of cases.

The other characteristic referred to as affecting the reaction of the human eye when viewing objects illuminated by "Osira" light is the limitation to certain wavelengths of the light radiated. This tends to affect visibility in several ways. Firstly, it reduces the effect known as chromatic aberration, *i.e.*, the relative inability of the eye to focus a wide range of colours sharply at the same instant. Owing to radiation from the lamp being mainly in the yellow and green regions of the spectrum and to the absence of red rays, the task imposed on the eye in this respect is reduced, and vision is correspondingly improved. Secondly, it reduces the disability due to diffraction, *i.e.*, the breaking up into their colour components of rays of light striking a sudden change of surface in an object such as a pit, a crack or a scratch.

Theoretically, monochromatic light should be ideal from both these points of view, but in so far as we are largely dependent on colour contrast for

Fig. 7. — Aeroplane construction carried out under mercury discharge lighting.

Fig. 8.—The quality of mercury discharge light simplifies the reading of fine measurements.

our power of seeing, the gain from the reduction in the number of wavelengths would be more than offset by the loss in colour contrast. The "Osira" light is a happy compromise between the two requirements, showing all colours except red to advantage yet limiting the radiations to a few strong lines.

THE ADVANTAGES OF "OSIRA" LIGHT.

The effect of these qualities is that, physiologically, vision is speeded up and the task of focussing the eye on the object is made easier. In practice it is found that with this form of lighting, almost all objects are far more clearly seen, simplifying the carrying out of industrial operations whether on the largest or the smallest scale. In foundries, owing to the power of the sand to reflect it to advantage, the general lighting penetrates to the bottom of sand moulds which before were adequately lit only by the use of portable lamps. In engineering works where operations are carried out on the inside of big cylinders, castings, etc., the light is reflected off the surrounding metal giving excellent visibility. In fine work the inspection of metal, glass, etc., for the most minute flaws is made easier than ever before—cracks scratches, pits in metal, flats on turned pinions and the like show up under "Osira" light so clearly that in many instances, inspection is simpler and more sure by artificial light than by natural daylight. Similarly, in manufacturing operations the point of a tool or the line of a scribe mark can be watched more clearly than ever before.

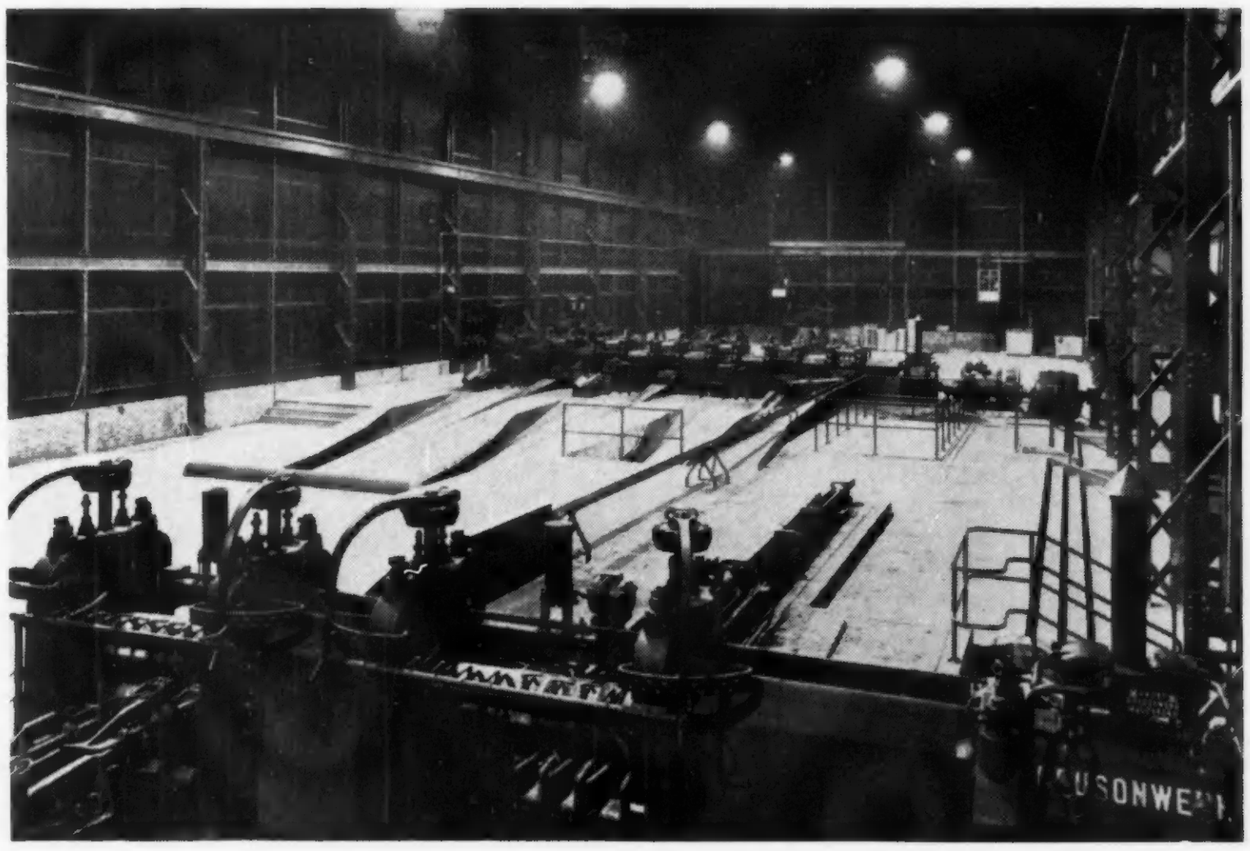

Fig. 9.—The high intensity of mercury discharge lamps renders them ideal for installation in lofty bays.

THE LIMITATIONS OF "OSIRA" LIGHTING.

What then are the limitations of "Osira" lighting? In referring to the colour of the light it should be clearly understood that advantage is claimed for it only as a source of general lighting where colour perception in the red end of the spectrum is not required. Clearly if colour perception is of prime importance the light is unsuitable. Some attempt has been made to increase the red light component but so far it has only been possible to give improvement in red content at the expense of considerable loss in overall efficiency and even then the extra percentage of red has been so small that in 99 cases out of 100 there would be no advantage from it. The hundredth case might be an operation where, for instance, the handling of coloured flexes was involved with the necessity of distinguishing surely between, say, a red and a brown flex. Under the corrected light a distinction might be possible where under the uncorrected light the colours might appear the same. Experiments have also been made by combining electric discharge lamps with tungsten lamps. Under certain circumstances this may be done to advantage, as for instance, for certain photographic processes. Generally speaking, however, the gain in colour by the addition of the tungsten lamps is not worth the loss in efficiency and acuity of vision. That every effort will be made by the inventors to improve the colour of

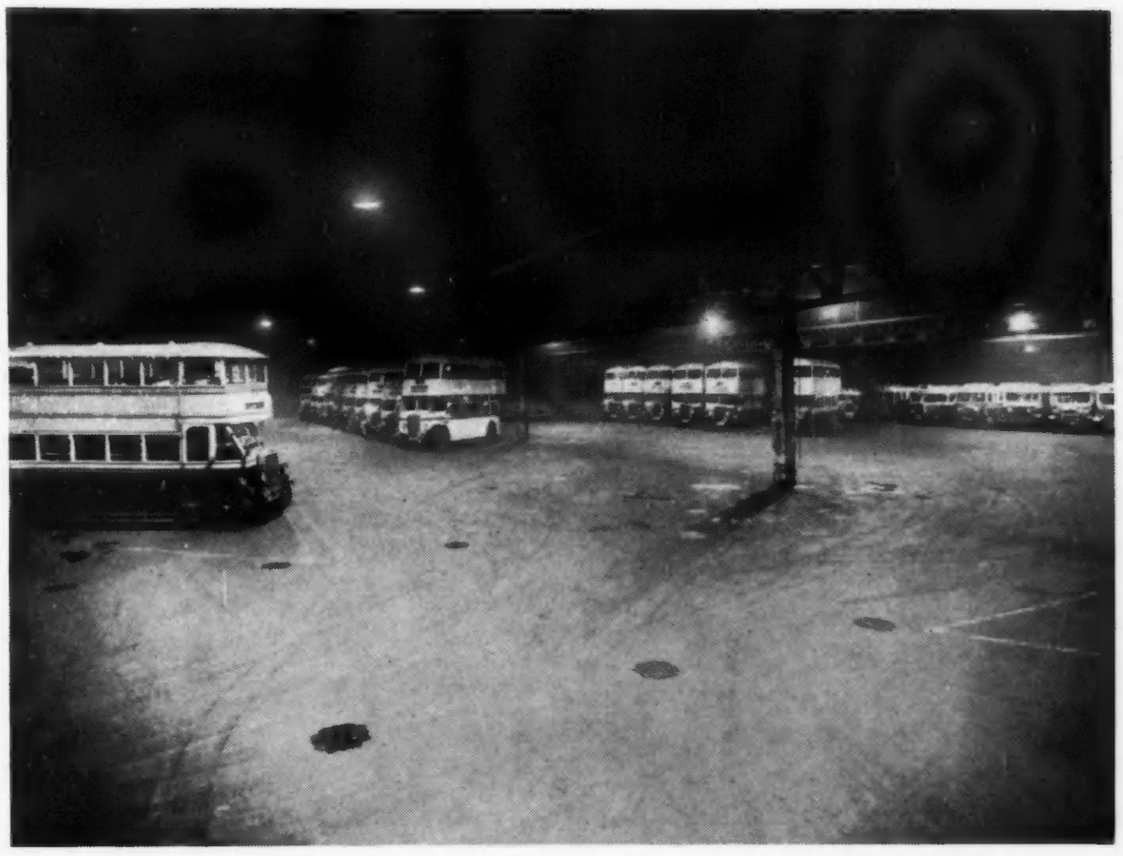

Fig. 10.—Many transport undertakings have adopted "Osira" lighting.

the light is obvious, but in the meantime industrialists will find on investigation that there are very few processes of manufacture where colour perception in the red end of the spectrum is of any importance,

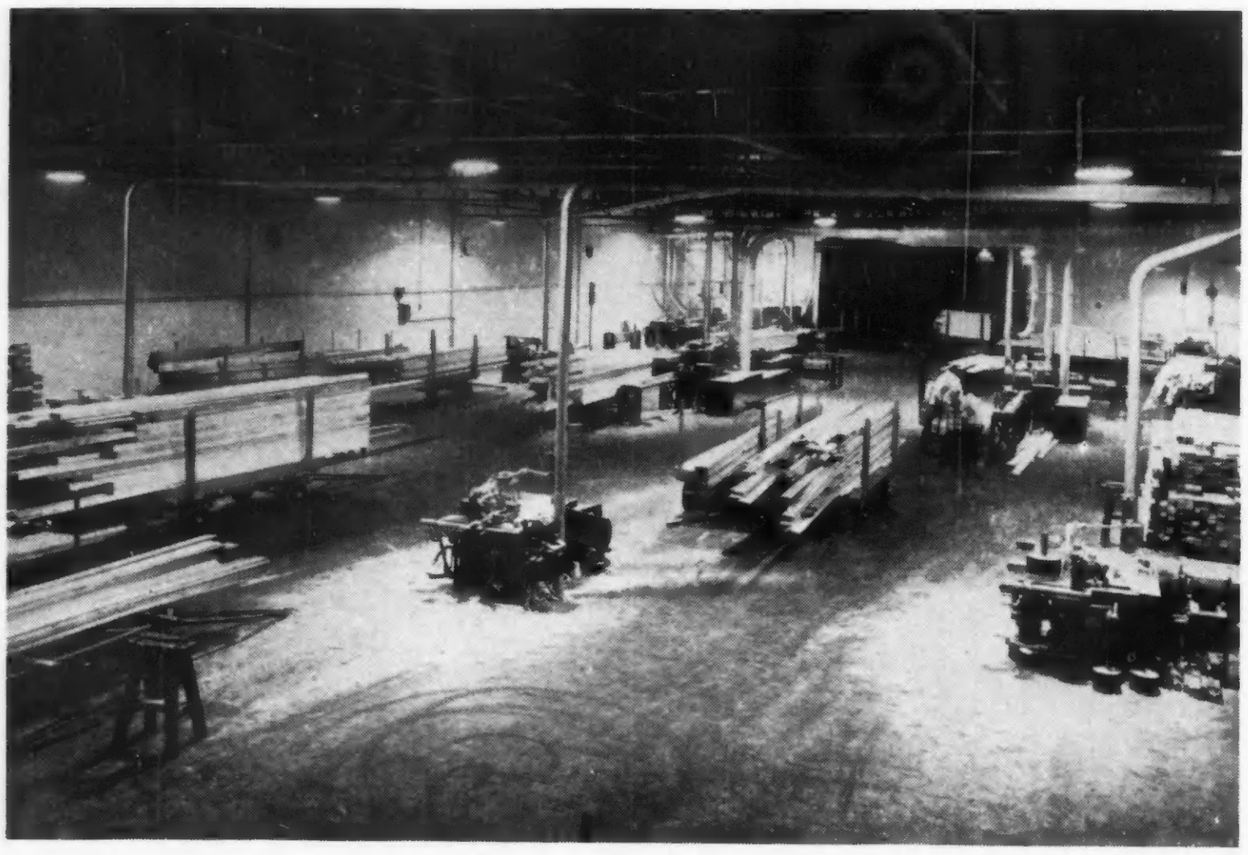

Fig. 11.—"Osira" lighting in a wood-working factory.

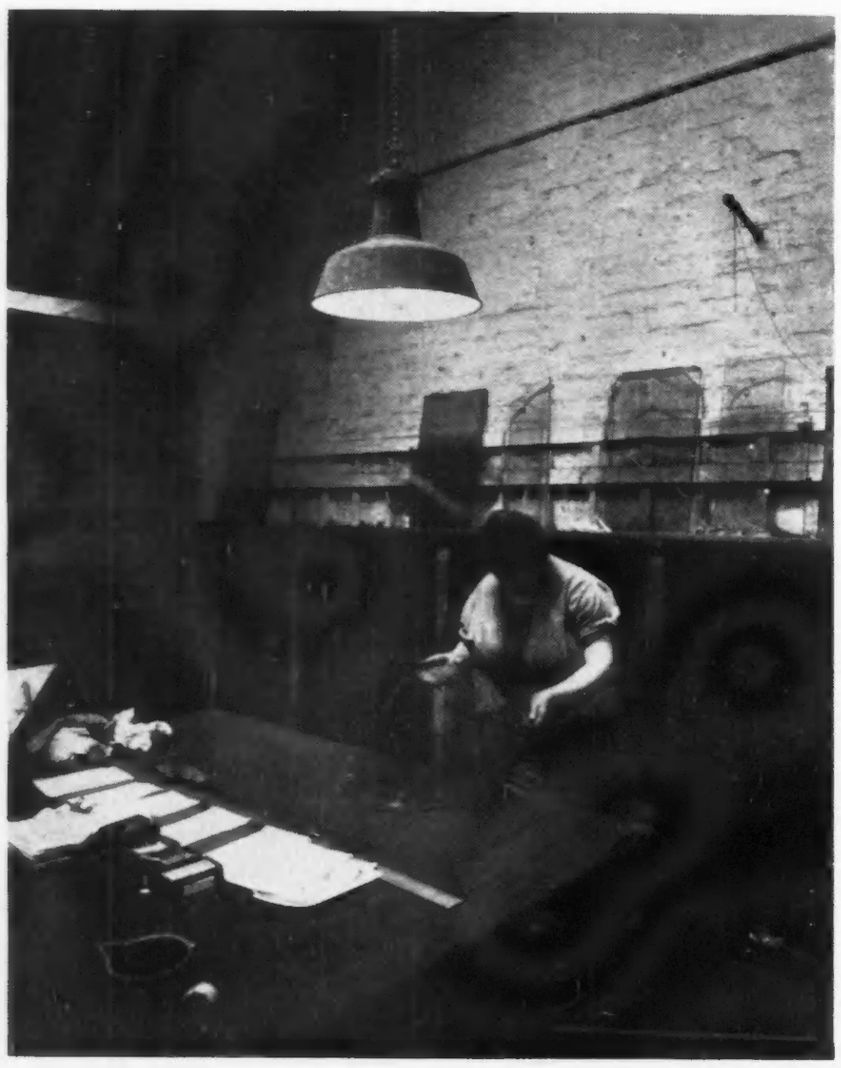

Fig. 12.—Flaws in glass are easily detected under high pressure mercury light.

and where true colour matching is required it is almost always carried out in a special section of the factory and under special lighting. In the factory as a whole, any question of colour will have been settled long before the material reaches the operative.

One other disability must be mentioned, although experience has proved it not to be nearly so serious as was at one time feared. This is the stroboscopic effect which takes the form of an apparent flicker due to the fact that the light goes completely out every half cycle. With the incandescent lamp this effect is present, but is only noticeable on relatively low periodicities as the incandescent filament does not have time to cool down appreciably between cycles. With the electric discharge lamp there is no such filament and the visual effect is that moving objects may appear to "dither," particularly if seen out of the corner of the eye. When applied to a rotating wheel, this "dither" may take the form of an apparent slowing down of the speed of rotation before such slowing down has really taken place, but in practice it has been found that there is no need for alarm on this account. The appearance of slow moving objects is not affected, while if any flicker is noticeable on faster machinery it may be almost entirely eliminated by wiring adjacent fittings on separate phases. By this means the periods of illumination of separate fittings overlap, ensuring a more constant illumination without noticeable flicker.

PSYCHOLOGICAL EFFECT.

Questions are sometimes asked as to whether high pressure mercury lighting has any bad effect on the eyes or health. Available evidence is definitely to the contrary. From a physical standpoint there is no ultra-violet light present of a wave length which will affect the eyes, while, psychologically, the effect in comparison with tungsten lighting is all in favour of the high pressure mercury. In spite of the blueness which might be expected to produce a cold effect, the light is definitely cheerful, and operatives quickly settle down to appreciate its advantages and would not change back to tungsten lighting if the choice were offered.

EQUIPMENT.

Before dealing with the question of costs, it may be well to say a few words as to the components of a high pressure mercury lighting installation. The essentials are reflector, lamp, choke, condenser and fuses.

As regards reflectors, while "Osira" lamps can be substituted in existing reflectors for high power tungsten lamps and show some definite gain, in order

to obtain the full benefit of high efficiency, even illumination and correct cut-off, the reflectors designed specially for use with them and described in the last issue of this Journal should always be employed. The function and electrical characteristics of the lamp, choke and condenser have also been previously described, but in the case of condensers, industrial conditions are not quite on a par with street lighting conditions, in that it is not necessary to have a separate unit for each lamp. In some factories central power factor correction may be installed and in such cases local condensers will be unnecessary, but even where local correction is employed single larger capacity units may give correction for a number of points. It is unwise, however, to have too big units as this would mean that if it were at any time desired to operate a few units only, there would be over-correction with a leading instead of lagging power factor. A useful size of condenser for industrial use is one of 80 mfd. controlling four 400 watt points or five 250 watt points.

While the use of fuses is optional, it is strongly recommended that each unit be fused separately to localise troubles in view of the time taken to re-strike when a lamp is switched off and then on again.

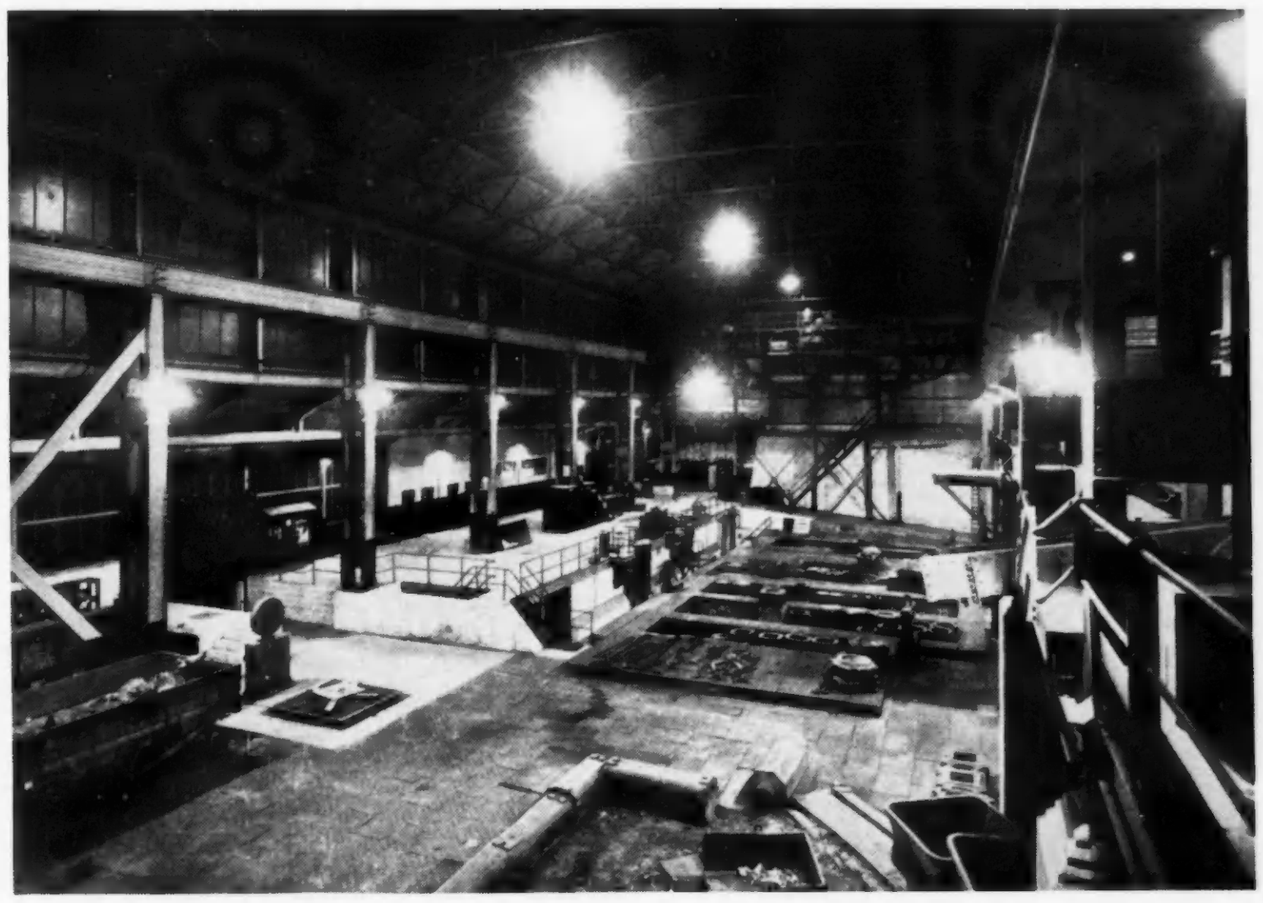

Fig. 13.—In this steelworks the mercury discharge lighting is automatically switched on by photoelectric cells.

THE ECONOMICS OF "OSIRA" LIGHTING.

The question of comparative cost remains to be discussed. Naturally the comparison varies with conditions as to current cost, burning hours, etc., and no hard and fast comparison is possible, but even at the most favourable rates for current the capital cost of an "Osira" installation is soon saved, while the advantage remains of improved quality of light at lower cost. It must be remembered that where specially low flat rates for current are in force, they are almost invariably accompanied by a kVA charge; and as it may be assumed in the majority of instances the peak demand will occur at a time when both lights and machinery are using current, a saving in kVA charge will result.

The accompanying tables give the savings per 400 watt "Osira" point at various rates for current and annual burning hours, and a fixed charge of £6 per annum per kVA of maximum demand. As the price for current increases the savings shown increase at an even faster rate. Taking the excess capital cost of such an installation over a tungsten lamp installation at £4 per point, it will be seen that in many cases a return on capital of 100 per cent per annum is obtained.

Taking all facts into consideration, it would appear that the invention of the mercury discharge lamp has put into the hands of industrialists a method of factory lighting which has great practical and economic advantages. Any form of illuminant which either reduces running costs or improves lighting conditions is worthy of serious consideration.

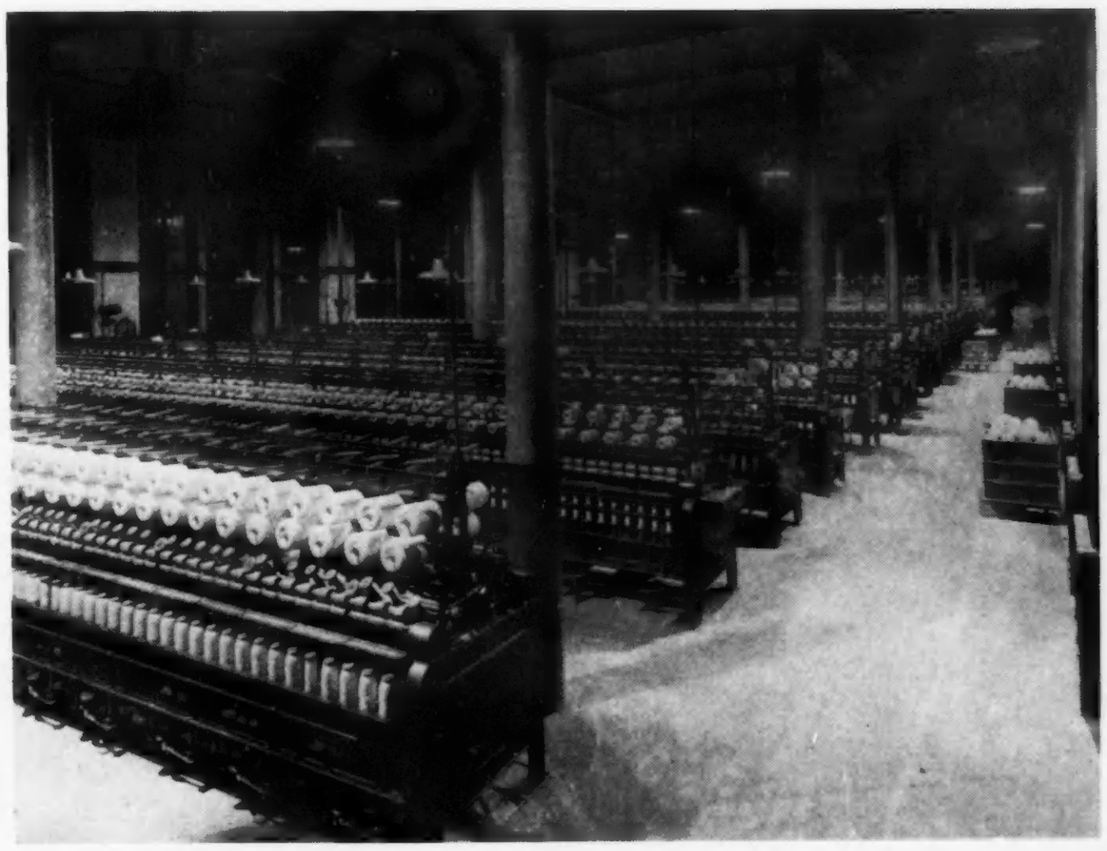

Fig. 14.—"Osira" lighting has many applications in the textile industry.

TABLE 1.

Economic relation between an "Osira" and a Tungsten installation for various charges per unit of electricity and for various burning hours per annum, on basis of one 500 watt Tungsten point and one 250 watt "Osira" point.

500 watt Tungsten v. 250 watt "Osira."

Burning hours per annum.	Price per unit.	kVA charge.	Saving in running costs per annum with "Osira."
		£ s. d.	£ s. d.
1000 hours	½d. charge	6 0 0	1 5 3
2000 ,,	½d. ,,	6 0 0	1 3 0
3000 ,,	½d. ,,	6 0 0	1 0 9
1000 ,,	¾d. ,,	6 0 0	1 10 1
2000 ,,	¾d. ,,	6 0 0	1 12 7
3000 ,,	¾d. ,,	6 0 0	1 15 1½
1000 ,,	1d. ,,	6 0 0	1 14 10½
2000 ,,	1d. ,,	6 0 0	2 2 2
3000 ,,	1d. ,,	6 0 0	2 9 5½
1000 ,,	2d. ,,	Nil	1 6 5½
2000 ,,	2d. ,,	,,	2 12 11
3000 ,,	2d. ,,	,,	3 19 4½

TABLE 2.

Economic relation between an "Osira" and a Tungsten installation for various charges per unit of electricity and for various burning hours per annum, on basis of one 1000 watt Tungsten point and one 400 watt " Osira " point.

1000 watt Tungsten v. 400 watt "Osira."

Burning hours per annum.	Price per unit.	kVA charge.	Saving in running costs per annum with "Osira."
		£ s. d.	£ s. d.
1000 hours	½d. charge	6 0 0	4 3 4
2000 ,,	½d. ,,	6 0 0	4 17 1
3000 ,,	½d. ,,	6 0 0	5 10 10
1000 ,,	¾d. ,,	6 0 0	4 15 5
2000 ,,	¾d. ,,	6 0 0	6 1 3
3000 ,,	¾d. ,,	6 0 0	7 7 1
1000 ,,	1d. ,,	6 0 0	5 7 6
2000 ,,	1d. ,,	6 0 0	7 5 5
3000 ,,	1d. ,,	6 0 0	9 3 4
1000 ,,	2d. ,,	Nil	4 6 3
2000 ,,	2d. ,,	,,	8 12 6
3000 ,,	2d. ,,	,,	12 18 9

It should be noted that the initial lumen output of a 250 watt "Osira" lamp is 12½% higher than that of a 500 watt tungsten lamp.

Fig. 15 (left).—For the illumination of works sidings and yards, mercury discharge lighting is particularly suitable.

Fig. 16.—Quick discrimination is obtained in coal and ore picking.

G.E.C. Journal

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IN THIS ISSUE.

—

ELECTRICAL PROGRESS
AND DEVELOPMENT
DURING 1934.

—

THE RECONSTRUCTION
AND ELECTRIFICATION
OF RYHOPE COLLIERY.

—

Vol. VI. No. 1. *February, 1935.*

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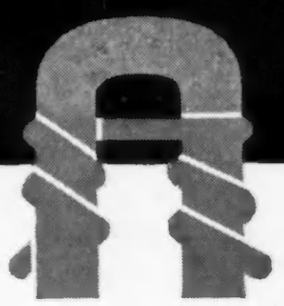

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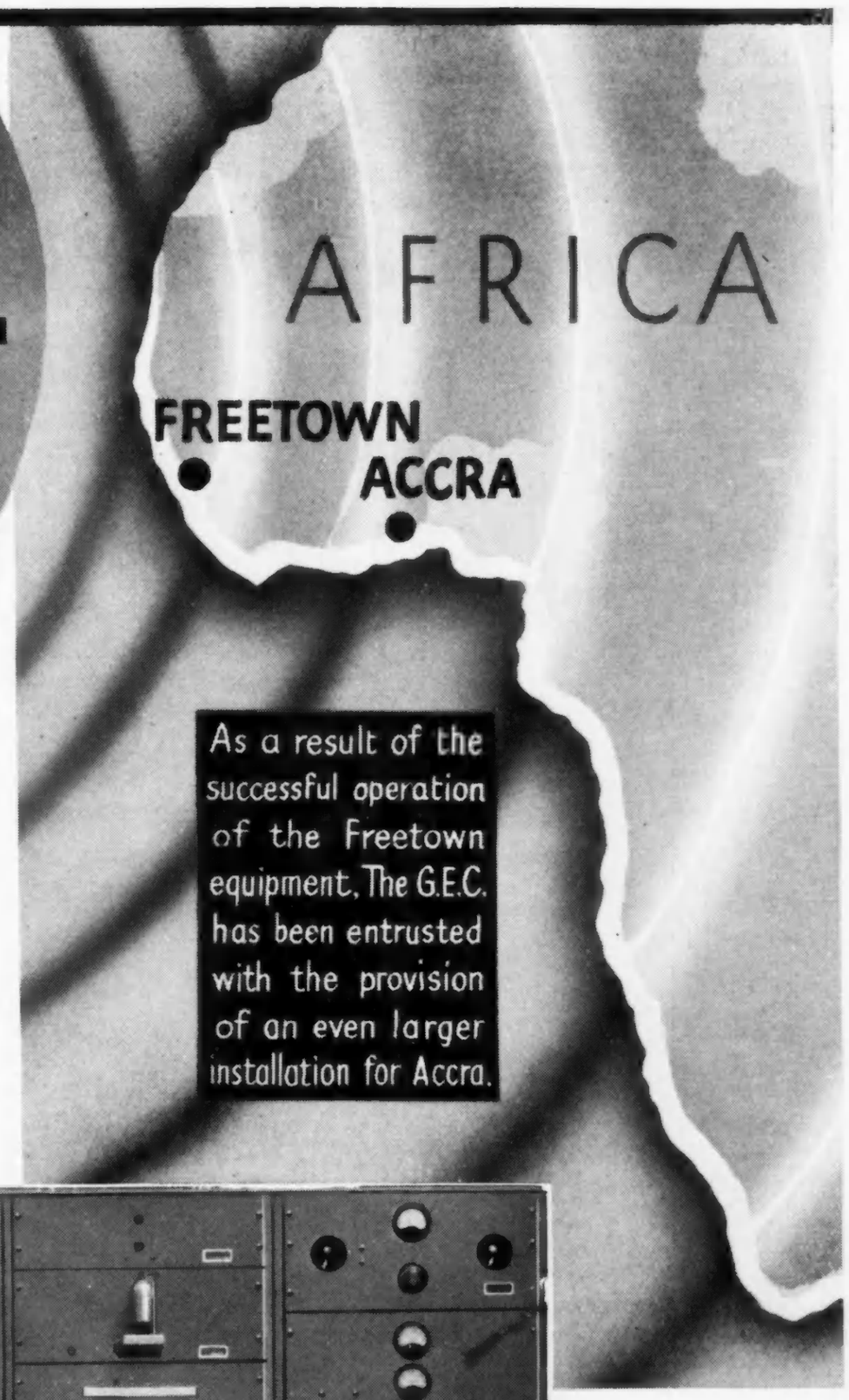
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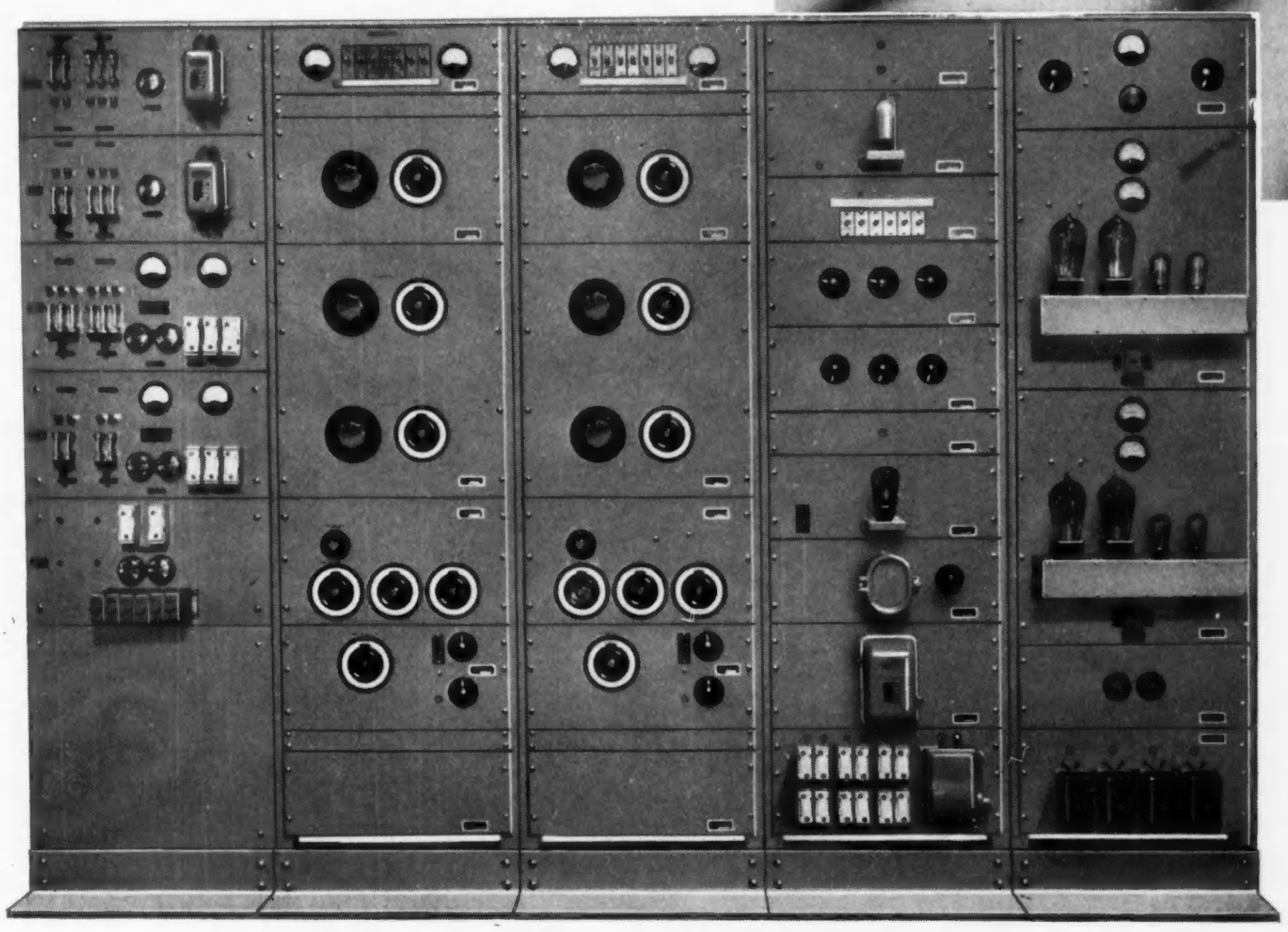

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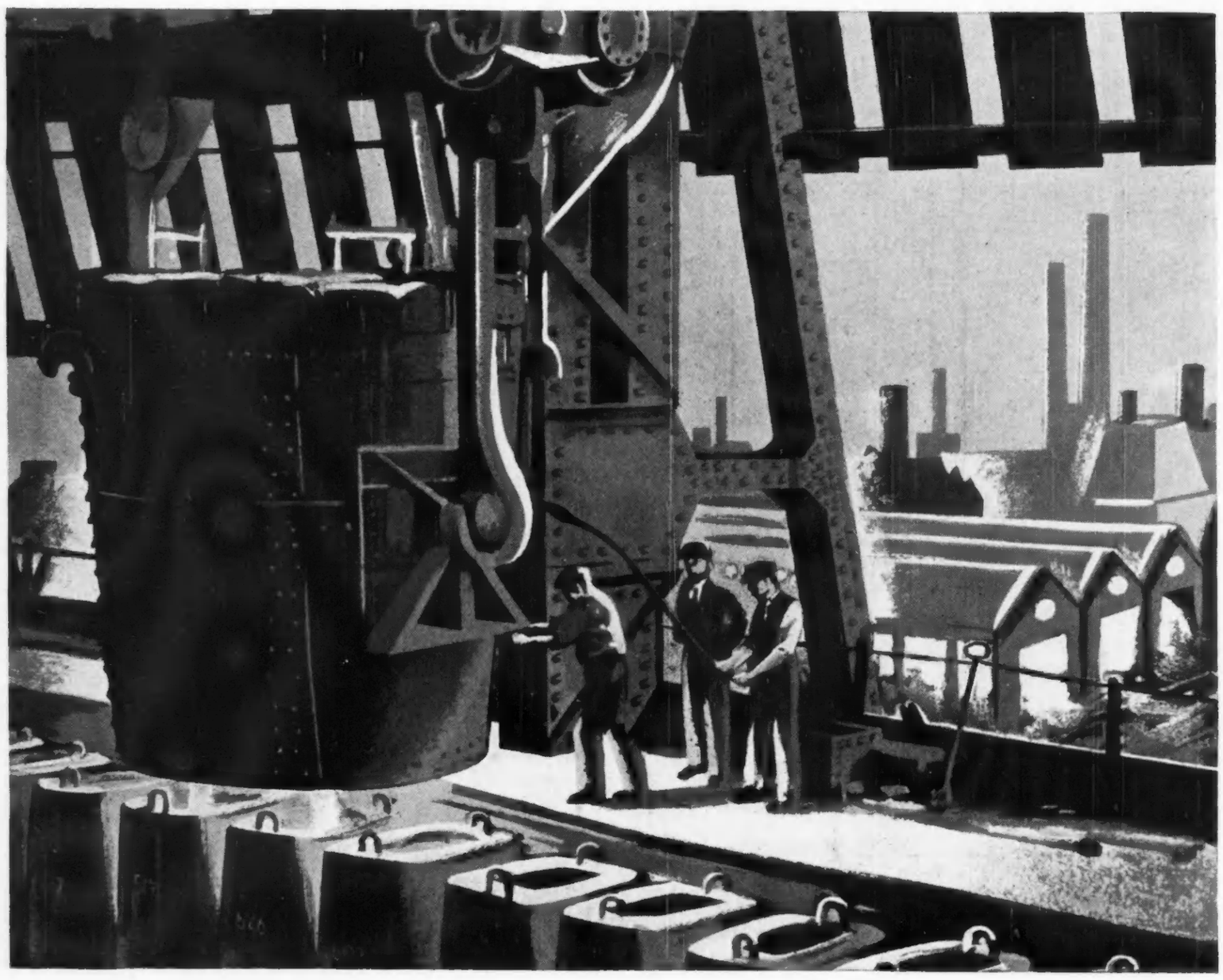

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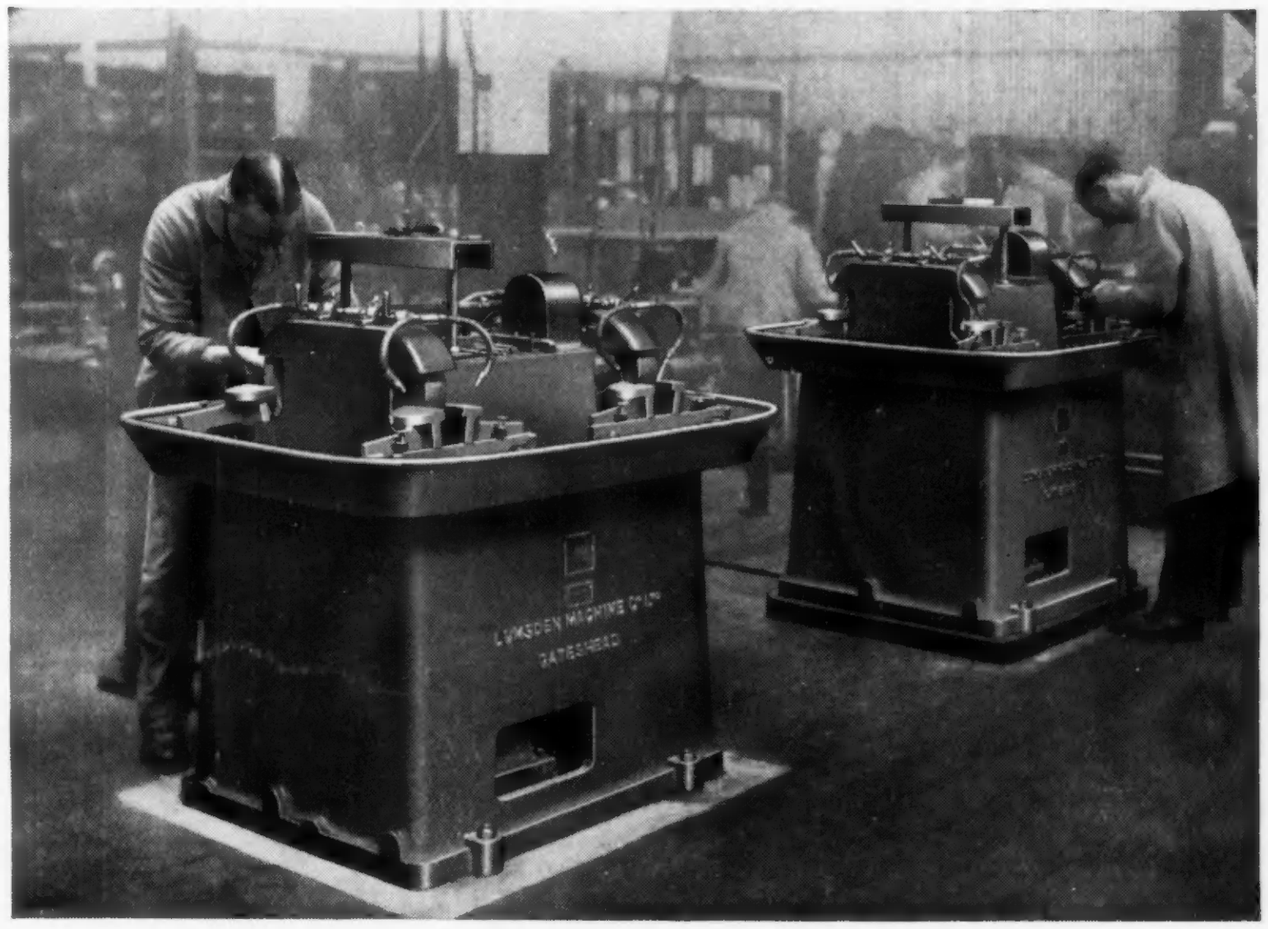

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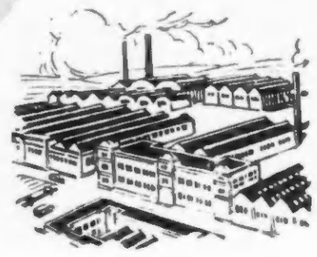

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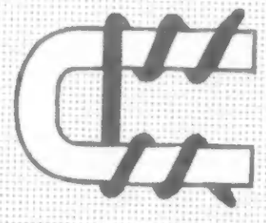

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GENERATION, DISTRIBUTION AND USE OF ELECTRICITY ON BOARD SHIP.

AN ELECTRICAL TEST RECORDER.

THE ELECTRIFICATION OF AN INDIAN TOBACCO FACTORY.

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Vol. VI. No. 2. *May, 1935.*

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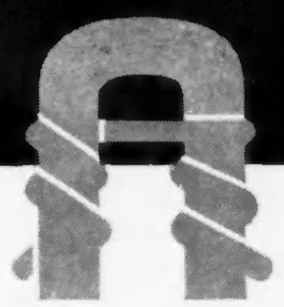

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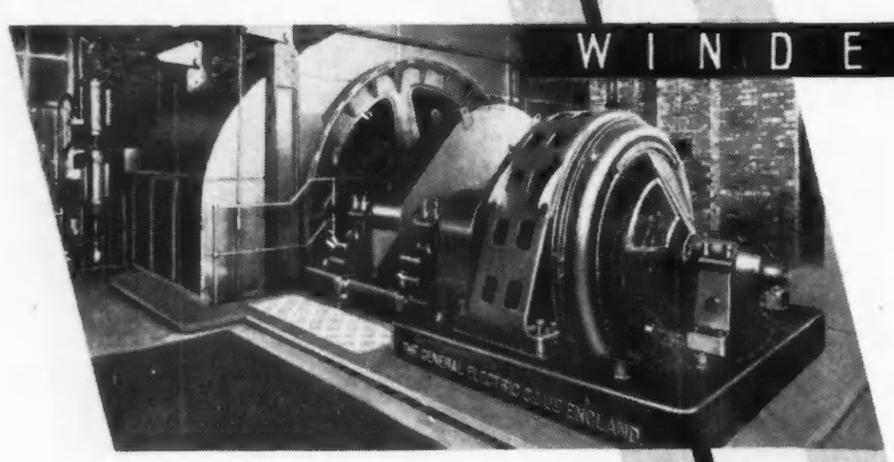
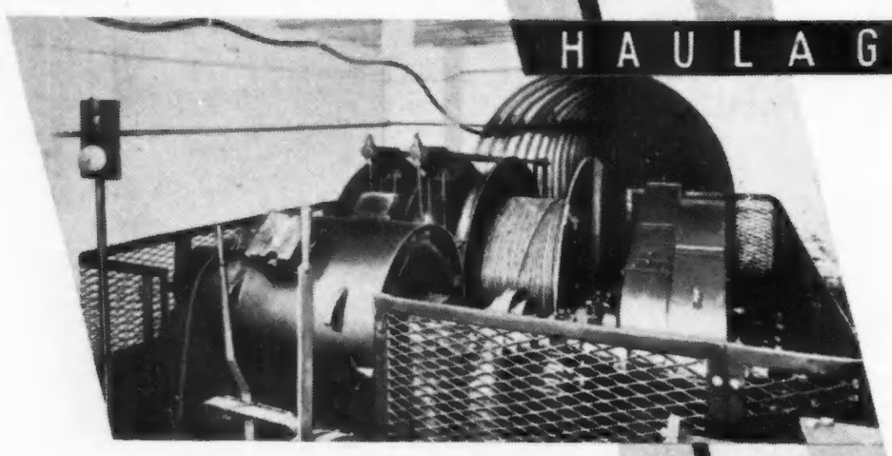


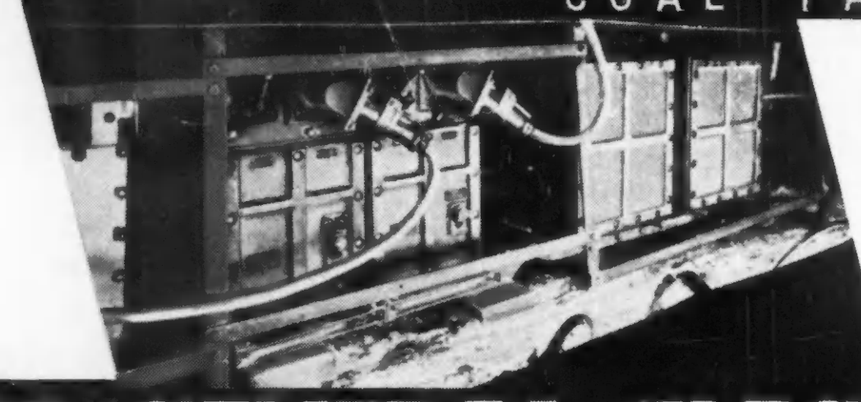
Underground haulage driven by 100 h.p. WITTON 3-phase motor

HAULAGE



View at the coal face. G.E.C. gate end boxes in the Harvey Seam

COAL FACE



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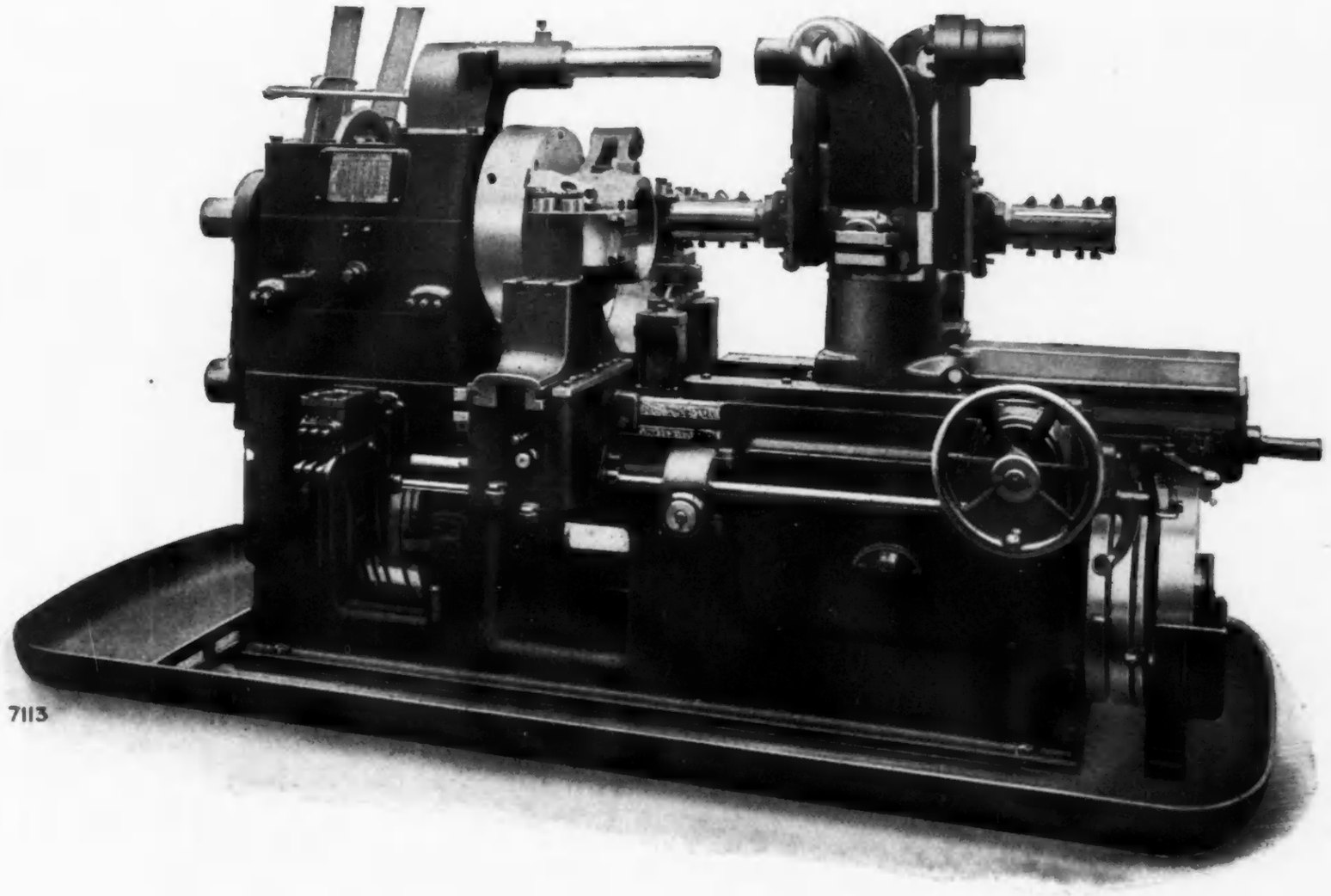

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The complete washery with screens, conveyors and the building was supplied and erected by Fraser & Chalmers Engineering Works, all electrical equipment having been manufactured at Witton Works.

"OSIRA"

REGD TRADE MARK

LAMPS

MADE IN ENGLAND BY THE G.E.C.

for

INDUSTRIAL LIGHTING

A section of the foundry at Ley's Malleable Castings Ltd., Derby, illuminated by "OSIRA" Lamps and G.E.C. dispersive reflectors.

For many industrial purposes, particularly those associated with the handling and inspection of metals, the bluish-white light from "OSIRA" Lamps has proved far superior to that of the ordinary incandescent Electric Lamp apart from the increased efficiency. The "OSIRA" Lamp gives initially $2\frac{1}{2}$ times as much light as a Tungsten filament lamp using the same amount of current.

COLVILLES "BIG FIVE"

"DALZO" Rust Resisting—Structures, Towers, Tanks, Sheets & Tunnel Plates. *(Approved by the B.O.T. for various parts of Life Boats).*

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"COLMO" High Limiting Creep Stress—Superheater Tubes, Etc.

"PYRO 68" Heat Resisting—Oil Cracking Plant, Etc. *(Non-scaling up to 800° centigrade).*

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"It's what its name implies, gentlemen. My hands don't have to wander more than 15″ one way and 23″ the other, to make the Asquith O.D. do everything I want."

"This product, gentlemen, has brains! Never did I know a machine tool answer the helm so easily and willingly. 'More per hour' is its watchword—and it's easy for me. A Radial Drill the likes of which I never before dreamed of—and that's from an operator with over 30 years' experience!"

Self-engaging spindle feed.
Single switch for driving and elevating motors.
Patent combined lock.
Electrical Reverse eliminating clutches.
Twelve speeds.
Four feeds, and
ONCE MORE
THE
"15 x 23" Control.

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WILLIAM ASQUITH, LIMITED

WELL ROAD WORKS, HALIFAX

THE GENERAL ELECTRIC CO.,LTD.

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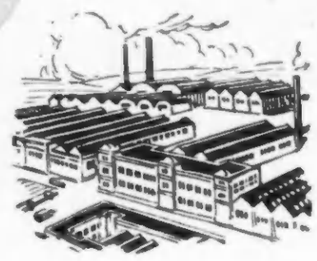

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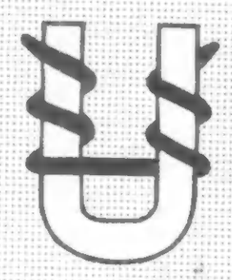

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G.E.C. Journal

IN THIS ISSUE.

THE DESIGN OF LIGHTING FITTINGS FOR "OSIRA" LAMPS.

VOLTAGE REGULATION OF A.C. TRANSMISSION AND DISTRIBUTION SYSTEMS.—PART I.

TURBO-BLOWERS AND TURBO-COMPRESSORS.—PART I.

THE ARTIFICIAL LIGHTING OF PICTURE GALLERIES.

GENERATION, DISTRIBUTION AND USE OF ELECTRICITY ON BOARD SHIP.—PART II.

NOTES ON MODERN ELECTRICAL MEASURING INSTRUMENTS.

Vol. VI. No. 3. *August, 1935.*

THE GENERAL ELECTRIC CO. LTD
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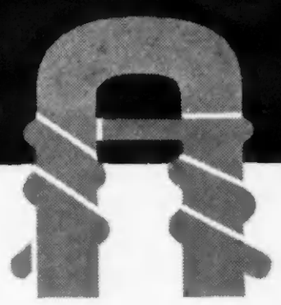
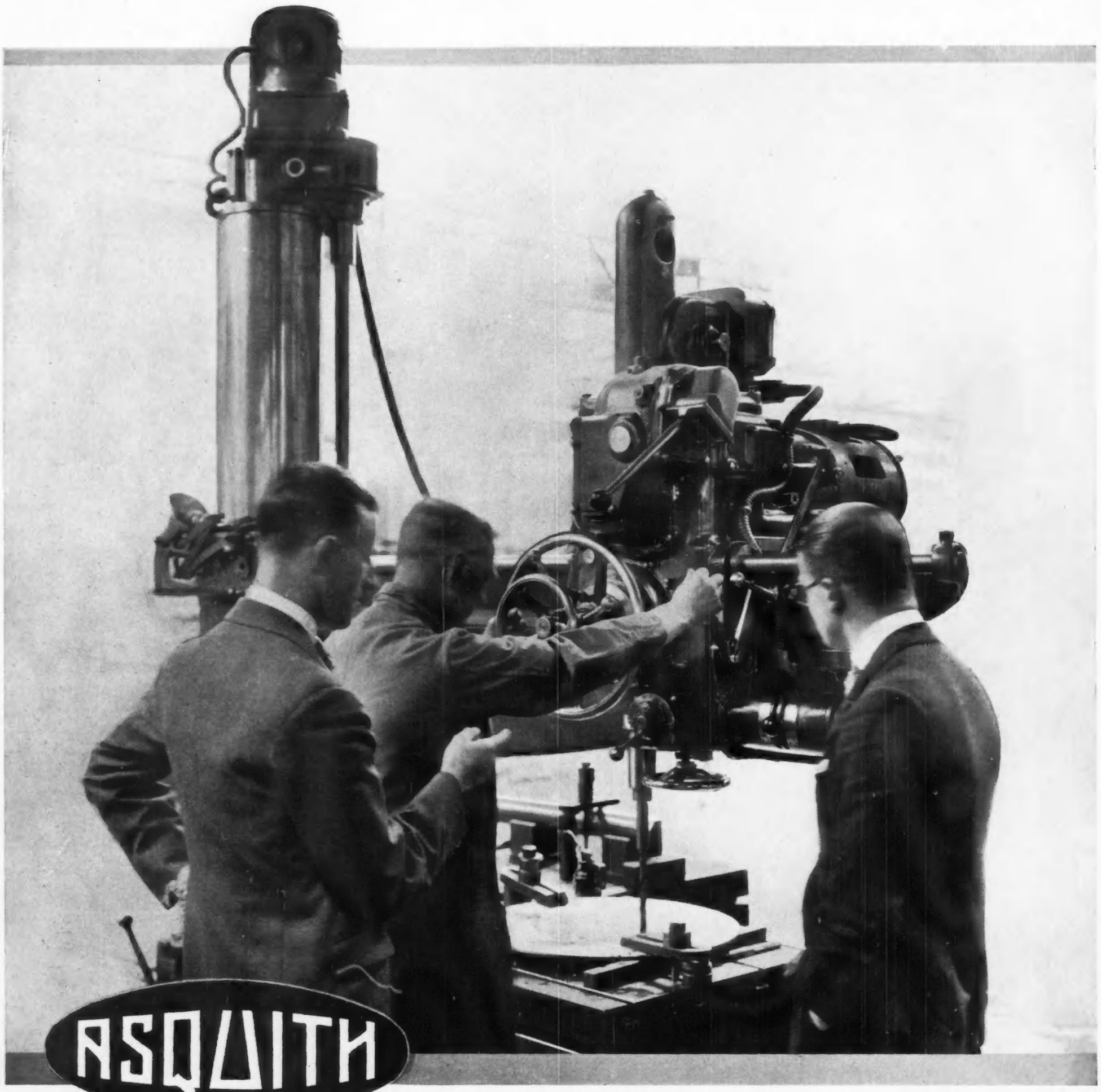


PIONEERS IN EVERY PHASE
OF ELECTRICAL DEVELOPMENT



"Just as good on the small work as on the bigger holes. Its rapid control is indeed remarkable. Your O.D. '15-23' I understand?"

"Yes, every control is on the slide and within an area of 15" × 23". Undoubtedly one of the secrets of success of the O.D. range."

"I have never seen hole to hole time nearer to vanishing point. The demonstration has been a revelation to me!"

"We invite you to join the band of O.D. Users. Over 500 of these machines are cutting costs all over the world. Why lag behind.?"

There is no other verdict . . . the Asquith O.D. is my final choice.

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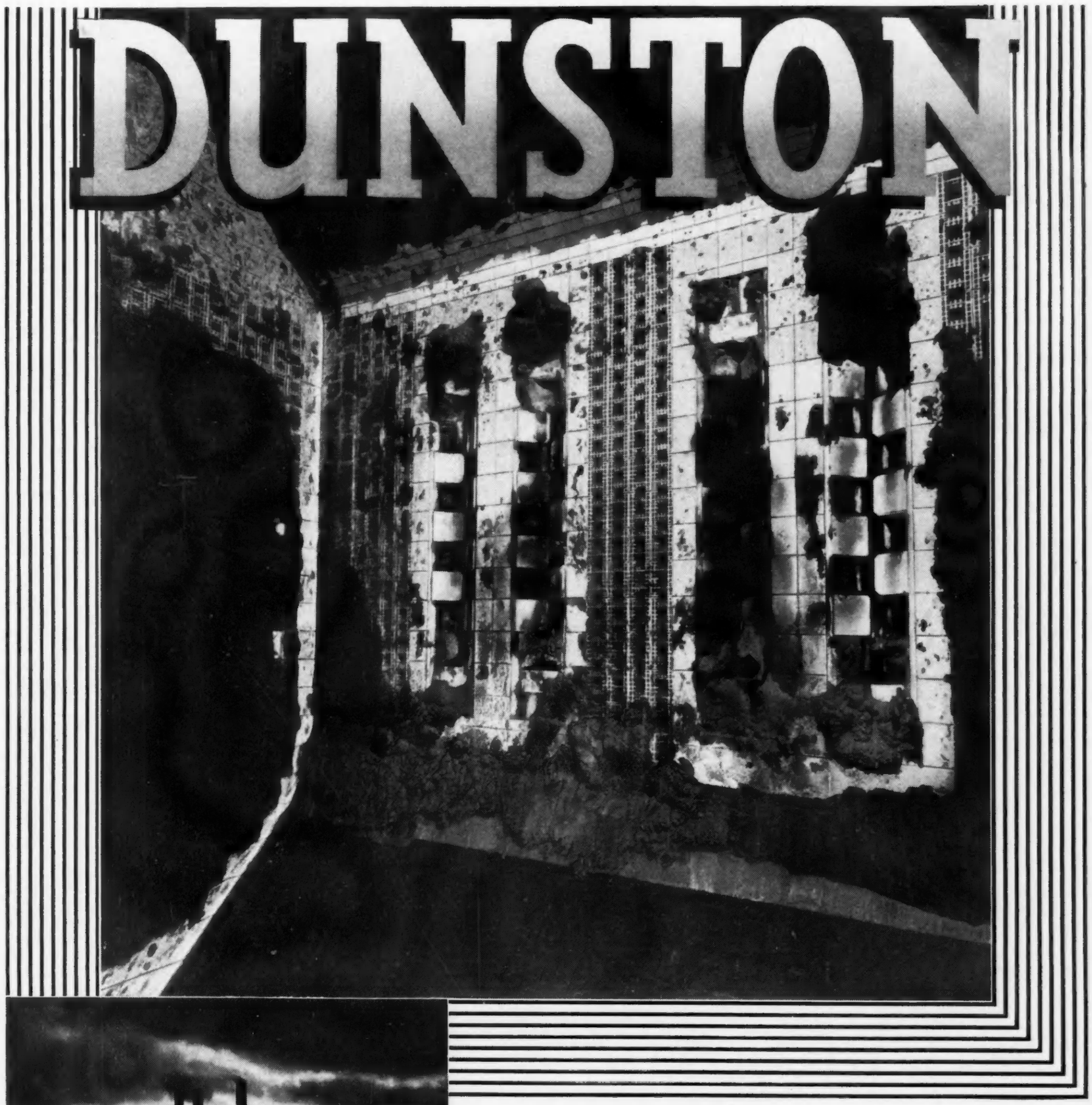

82 B. & W. Boilers have been supplied for the major stations of the North-Eastern Electric Supply Co. Ltd., giving a total normal capacity of nearly 4,000,000 lbs. of steam per hour.

THE NORTH-EASTERN ELECTRIC SUPPLY CO. LTD.,

has always made the utmost use of the latest developments when designing new stations, and therefore it is natural that the Dunston 50 Cycle Station which commenced operation in 1933 should possess a number of unique features.

12 B. & W. Boilers are installed for a total maximum capacity of about 1,750,000 lbs. of steam per hour at 625 lbs. per square inch and 840° F. All these boilers are equipped with complete Bailey Furnaces, 8 of them being fired with B. & W. Style 28 Stokers and 4 being pulverised fuel fired. Six of the boilers incorporate steam reheaters and all have superheaters, economisers and air heaters.

The upper illustration shows the interior of the Bailey Furnace on one of the pulverised fuel fired boilers, which is equipped with Calumet burners.

The illustration on the left gives an impression of the station as seen from the North bank of the River Tyne.

Our Reprint No. 1173 of a technical paper article describing this installation will be sent on request.

BABCOCK & WILCOX LTD. 34 FARRINGDON ST., LONDON, E.C. 4

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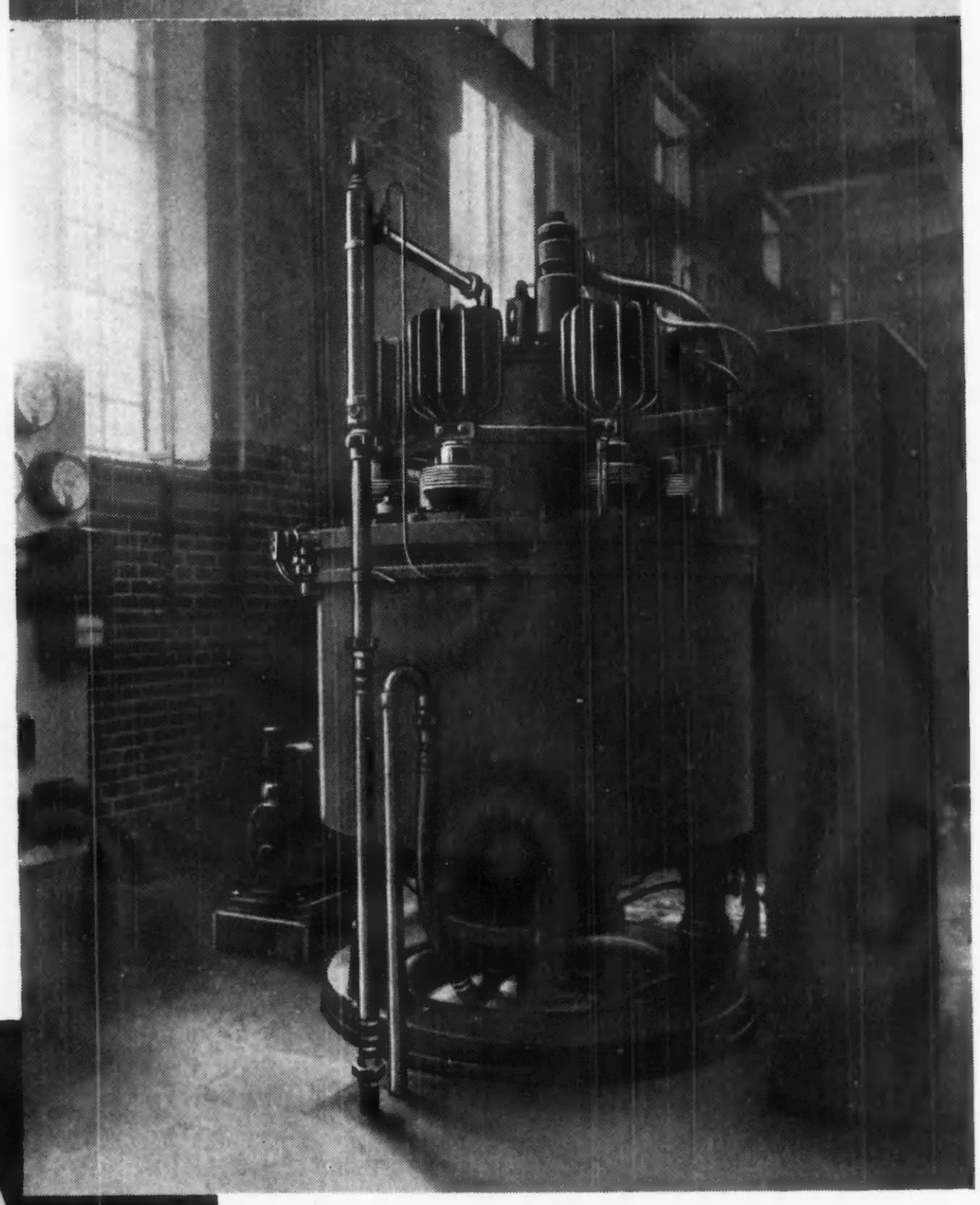
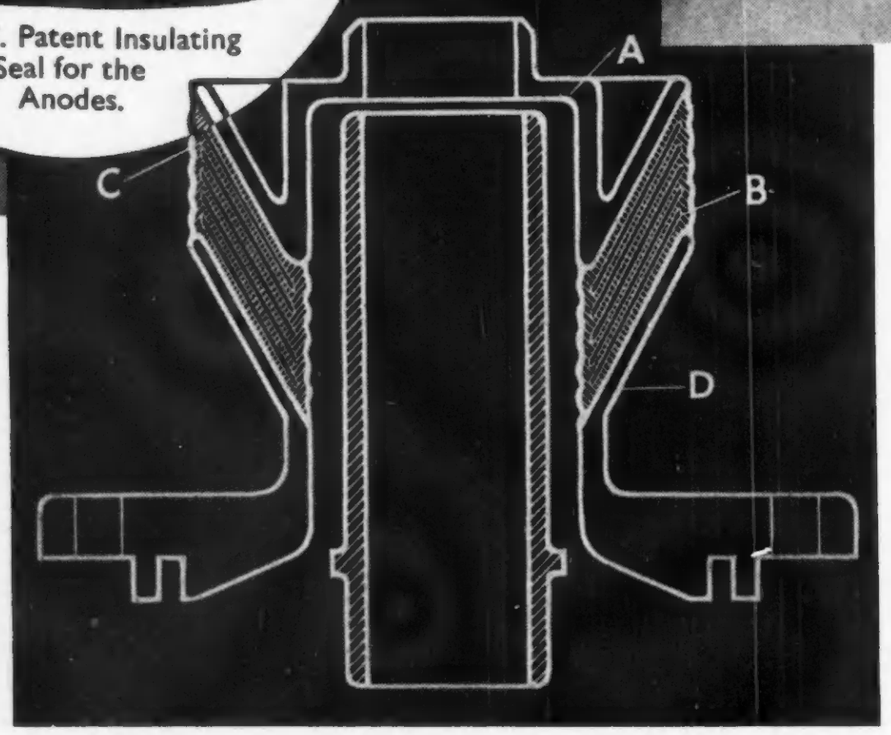
G.E.C. MERCURY ARC RECTIFIERS

THE FIRST BRITISH MADE MERCURY ARC RECTIFIER INSTALLED ON THE CONTINENT OF EUROPE

G.E.C. Patent Insulating Seal for the Anodes.



G.E.C. 1,200 kW mercury arc rectifier 565/625 volts installed at Copenhagen in one of the municipal sub-stations.



The highest possible efficiency is ensured by the G.E.C. Patent insulating seal which is perfectly vacuum tight.

The G.E.C. patented seal consists of a number of thin mild steel cones, B, separately coated with a special vitreous enamel, C. After assembly of the cones and top and bottom members, A and D, the whole is fused up solid in an electrically heated oven. The result is a strong unit having a very high dielectric strength. It is perfectly vacuum-tight, and can be bolted down in the simplest possible way to the top plate of the rectifier, and this, together with an improved form of metal to metal joint, enables rubber and mercury seals to be eliminated.

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Herbert No. 1 Self-contained Motor-driven Plain Milling Machines in our Testing Bay.

THIS is the new Herbert No. 1 Self-contained Motor driven Plain Milling Machine.

It fills the demand for a high-class machine for milling large quantities of small parts at high rates of production.

It has a roller-bearing spindle ensuring accuracy and rigidity; the final drive by belt eliminates vibration under cut.

Can be supplied with alternative speed and feed ranges, one to deal successfully with cast-iron and non-ferrous metals or a lower range for use when steel in addition to cast-iron is being machined.

The machine is easy to install, easy to operate and will last for years under the most arduous production conditions.

Supplied either with hand feeds of $7'' \times 3\frac{1}{8}'' \times 7''$ or with electrical automatic longitudinal feed, capacity $10'' \times 4'' \times 7''$.

HAND FEED MACHINES CAN BE DELIVERED IMMEDIATELY.

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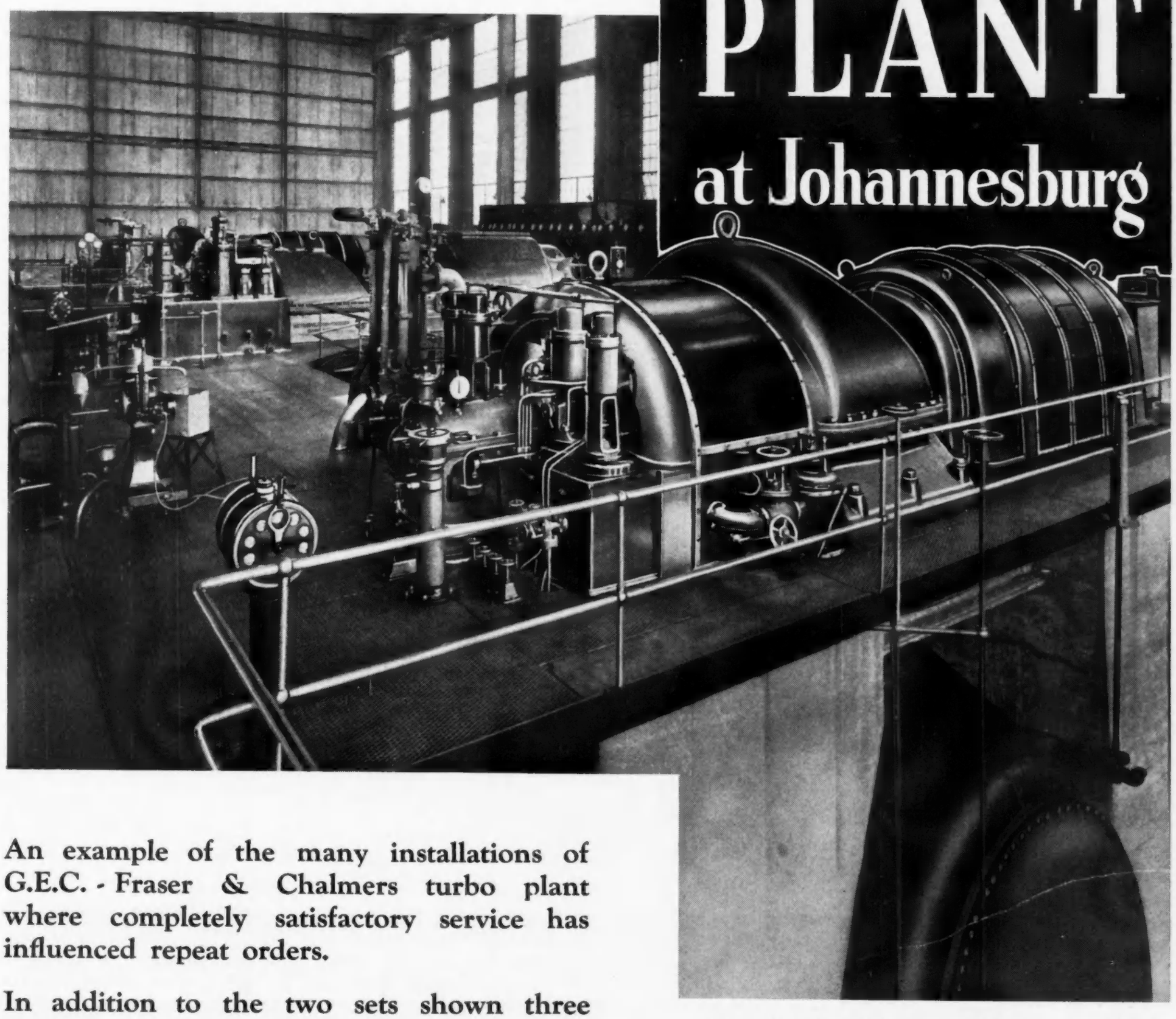
TURBO PLANT

at Johannesburg

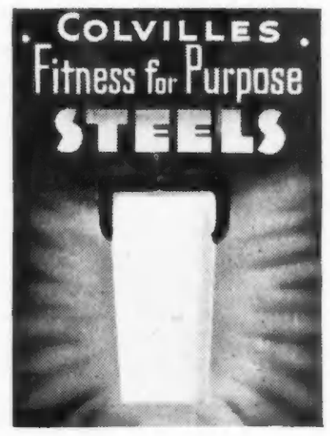


An example of the many installations of G.E.C. - Fraser & Chalmers turbo plant where completely satisfactory service has influenced repeat orders.

In addition to the two sets shown three further sets have been ordered for this power station, one of 12,500 kVA and two of 20,000 kVA output.

View in Johannesburg municipal power station showing two G.E.C. - Fraser & Chalmers 12,500 kVA, 3,000 r.p.m. turbo alternators.

COLVILLES "BIG FIVE"



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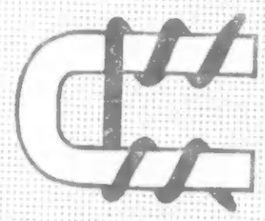

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IN THIS ISSUE.

THE ELECTRIFICATION OF A NEW CONTINUOUS HOT ROLLED STRIP MILL.

THE DESIGN OF PRECISION COMMERCIAL PHOTOELECTRIC PHOTOMETERS.

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RECENT DEVELOPMENTS IN ELECTRIC THERMAL STORAGE COOKERS.

ELECTRIC WINDER FOR THE CHAMPION REEF GOLD MINES OF INDIA.

THE USE OF HIGH PRESSURE MERCURY DISCHARGE LAMPS IN INDUSTRIAL LIGHTING.

Vol. VI. No. 4. *November, 1935.*

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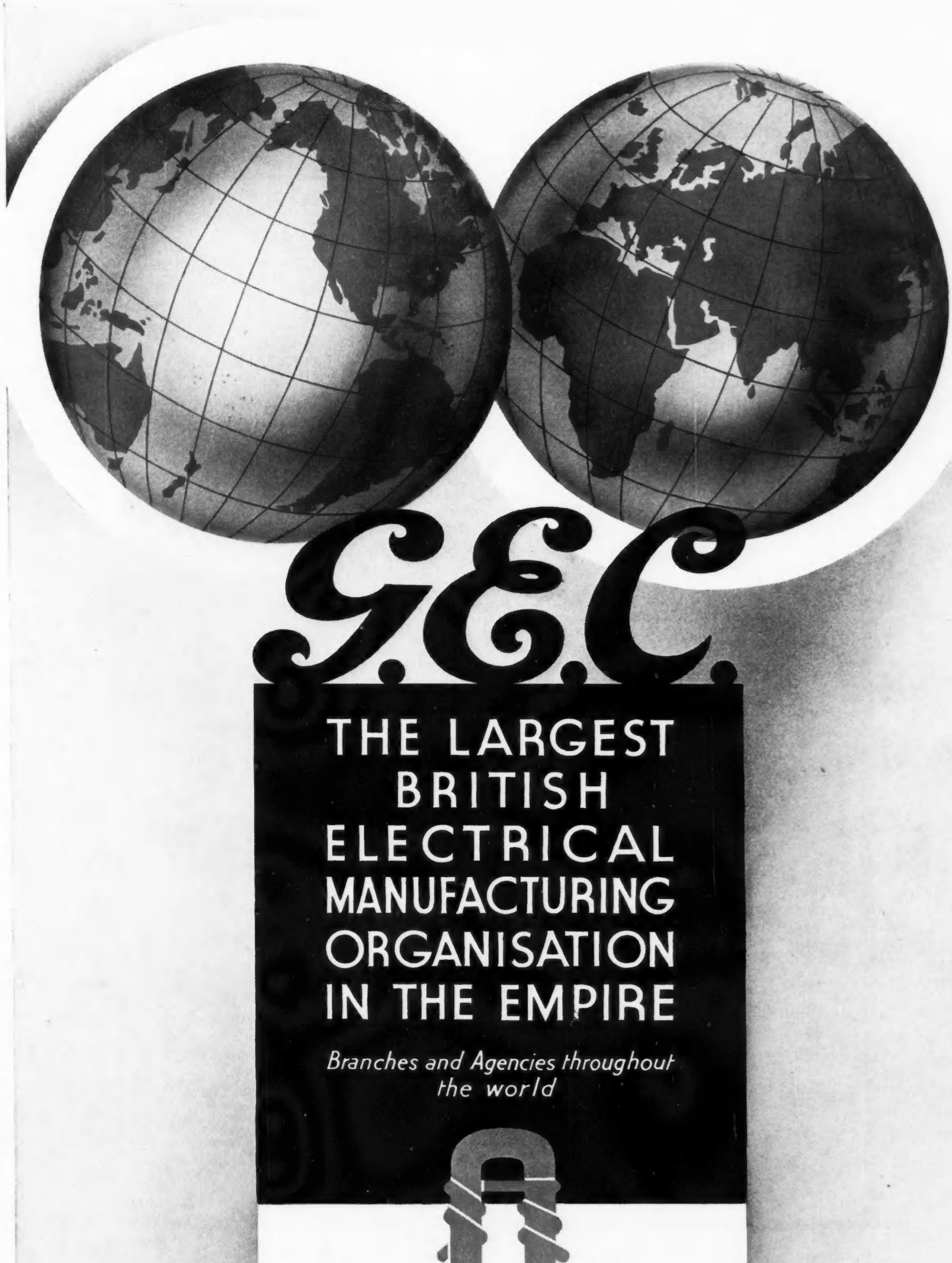
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issue from time to time reprints of technical articles of which the following are typical. Copies of these and others can be obtained on application to the nearest branch office or representative.

No. 1141a

RESEARCH WORK AT RENFREW.

No. 1179

THE REDUCTION OF COAL SAMPLES FOR ANALYSIS.

No. 1182

BOILER INSPECTION DURING MANUFACTURE AND ERECTION.

No. 1192

MODERN METHODS OF INDICATING WATER LEVEL IN BOILER DRUMS.

The above are typical of the development work which lies behind any Babcock and Wilcox installation.

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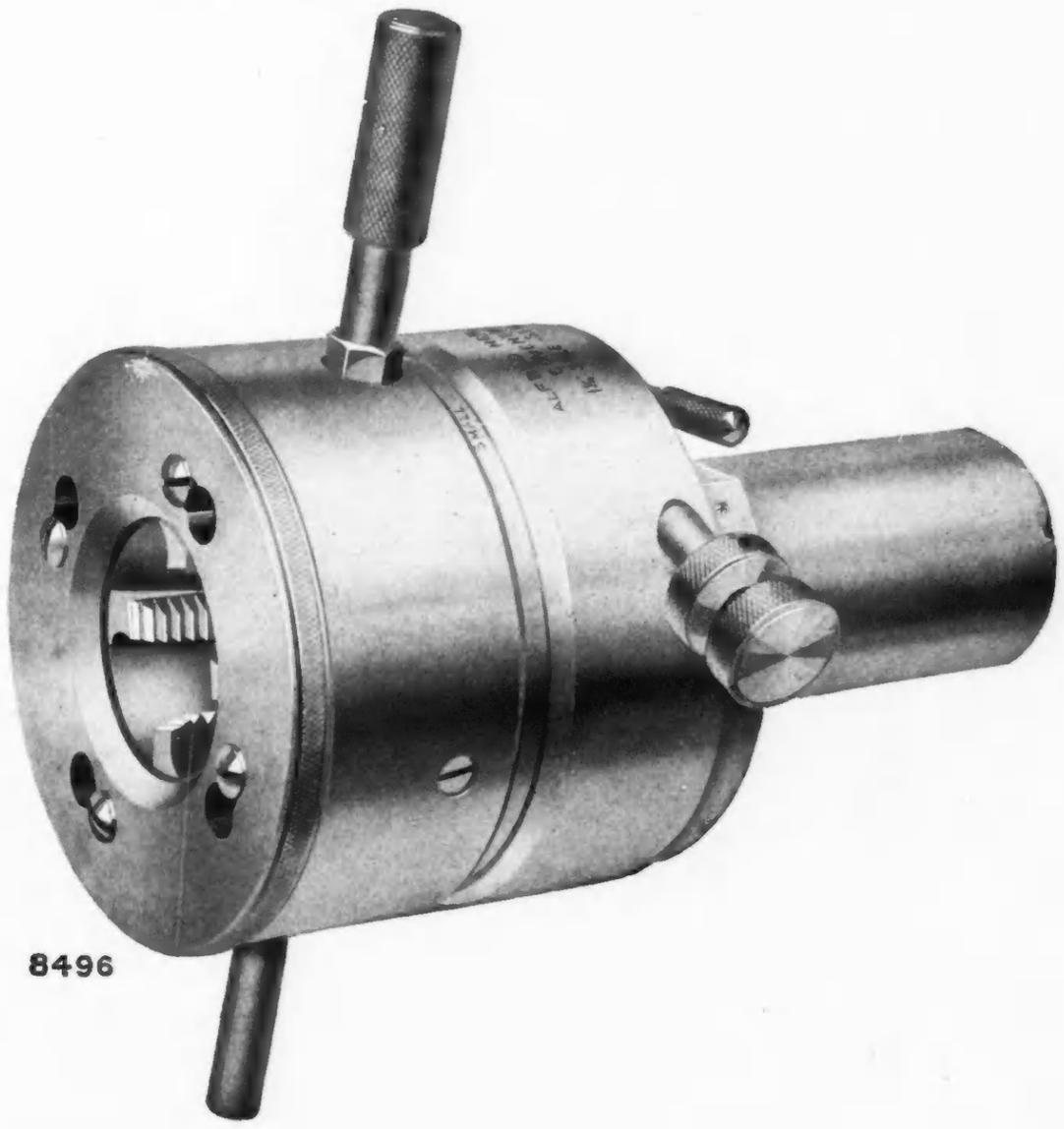

COVENTRY SELF-OPENING DIEHEADS

THE world's standard threading tool.

Ideal for all normal threading operations, die changing and sharpening are the simplest possible operations.

Guaranteed to cut accurate threads on all materials that can be threaded.

Coventry Patent Zonic Lapped dies cut threads to B.S.I. close fit tolerances.

Ten sizes for standard threads from $\frac{1}{4}''$ to $4\frac{1}{4}''$.

Two sizes for fine threads $2\frac{1}{2}''$ and $3\frac{1}{2}''$.

For long runs, particularly on material which is hard to cut, we supply Coventry Tangic Diehards which use tangential dies giving exceptionally long die life.

Two types : Stationary . . $\frac{9}{16}''$, $\frac{3}{4}''$ and $1\frac{1}{4}''$.
Rotary . . . . . $\frac{9}{16}''$.

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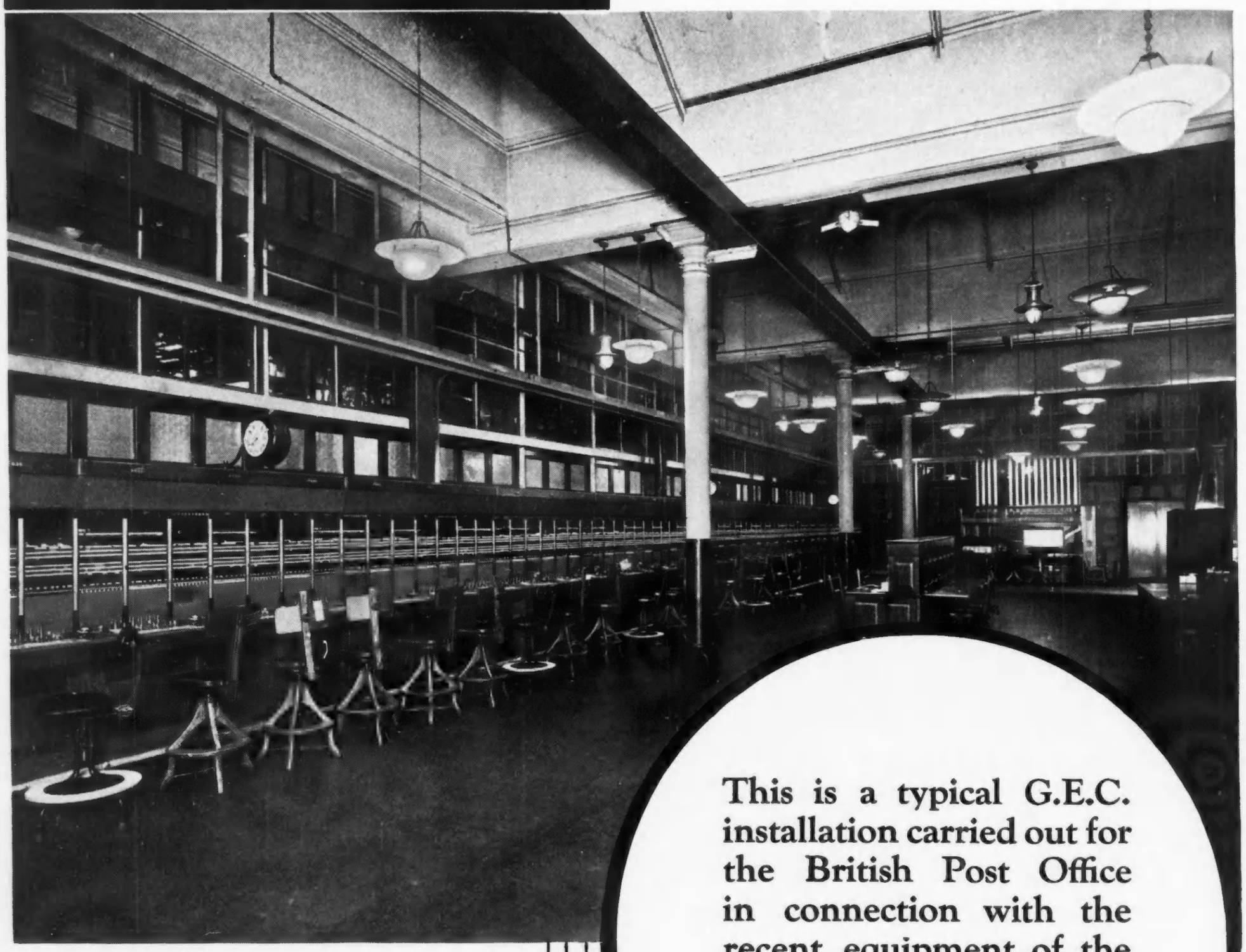


Demand switchboard at Liverpool zone trunk exchange manufactured and supplied by the G.E.C.

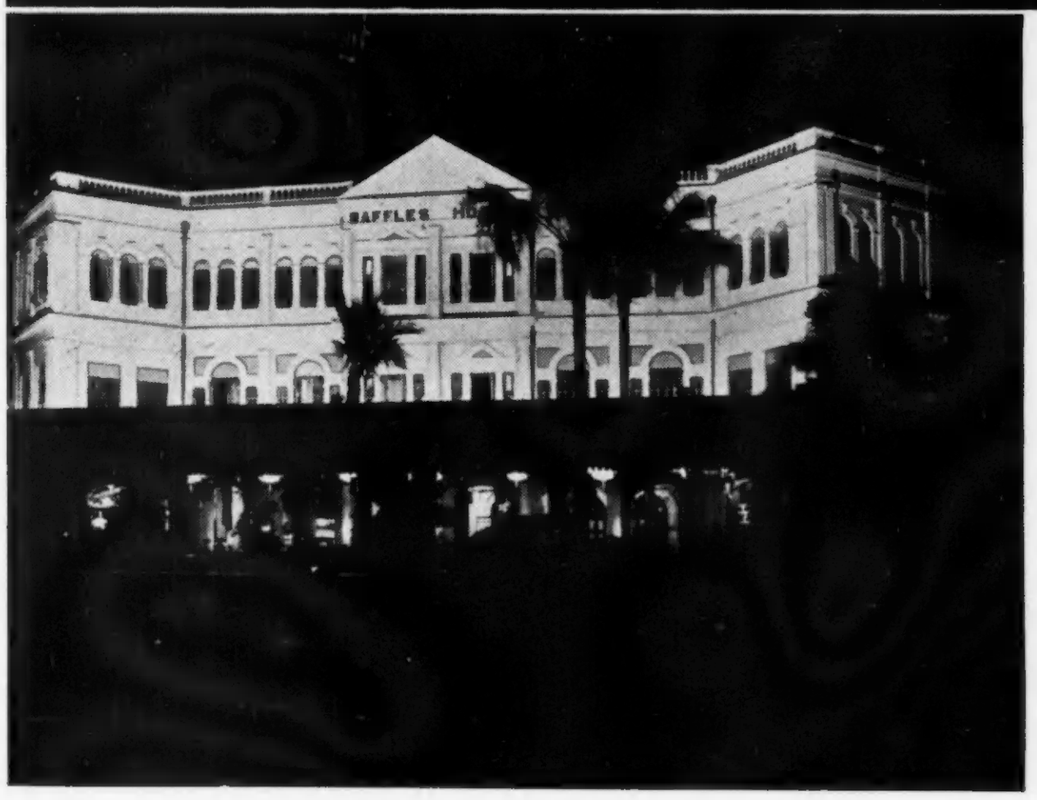
This is a typical G.E.C. installation carried out for the British Post Office in connection with the recent equipment of the Trunk Telephone network for the provision of "demand" service throughout Great Britain.

G.E.C.

FLOODLIGHTING OVERSEAS

GOVERNMENT HOUSE, CALCUTTA.

Top inset view:
HOUSES OF PARLIAMENT, CAPE TOWN
floodlighted by G.E.C. Projectors and OSRAM LAMPS



RAFFLES HOTEL, SINGAPORE
with G.E.C. floodlighting.

G.E.C. pre-eminence in the field of electric lighting has been strikingly emphasized by the Jubilee celebrations throughout the Empire. These examples of G.E.C. Floodlighting in South Africa, India and Malaya are typical of many G.E.C. installations overseas.

"Just as good on the small work as on the bigger holes. Its rapid control is indeed remarkable. Your O.D. '15-23' I understand?"

"Yes, every control is on the slide and within an area of 15″ × 23″. Undoubtedly one of the secrets of success of the O.D. range."

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There is no other verdict . . . the Asquith O.D. is my final choice.

Send for new catalogue R48, to

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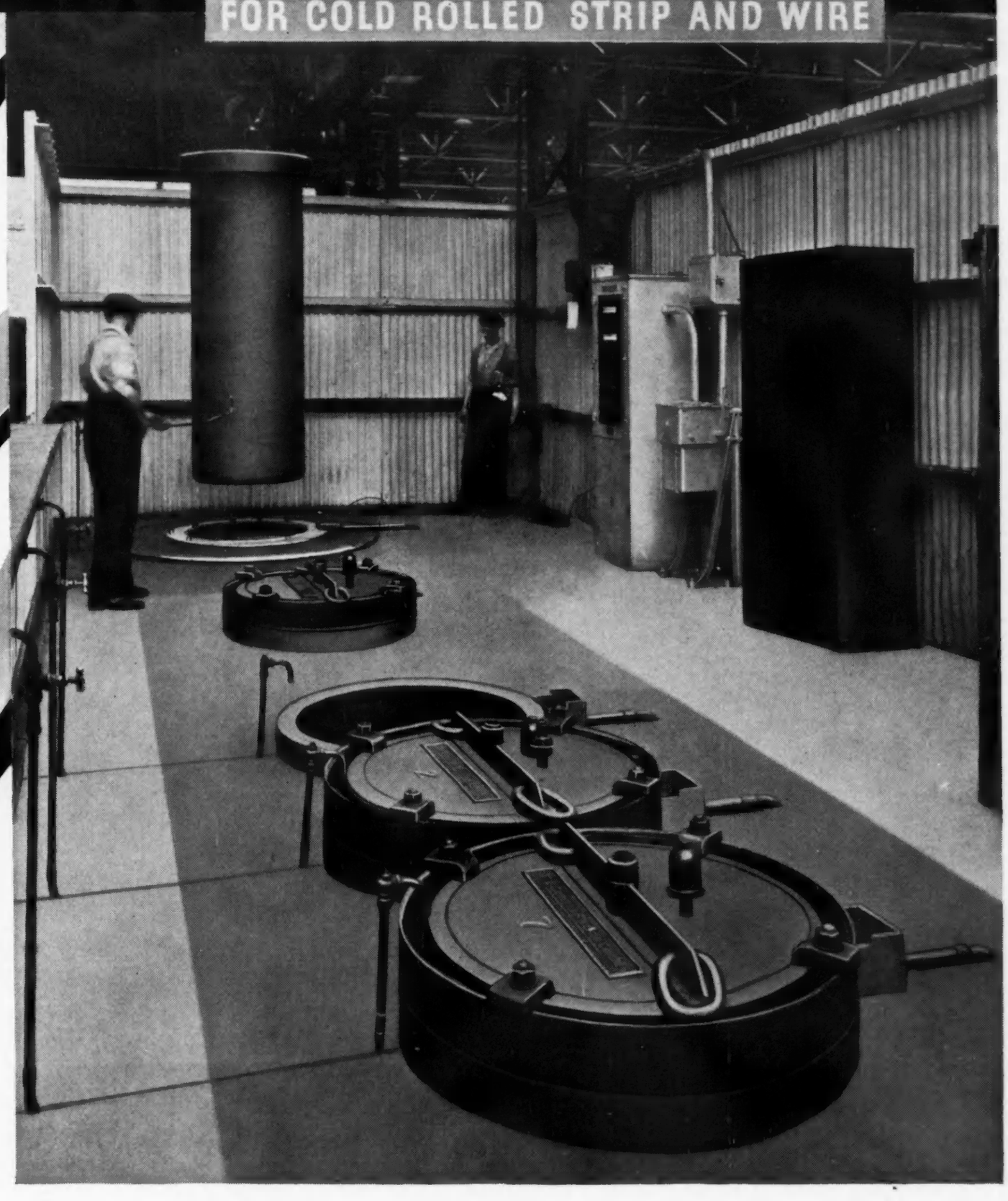
G.E.C. ELECTRIC FURNACES FOR BRIGHT ANNEALING by the Grünewald Process

FOR COLD ROLLED STRIP AND WIRE

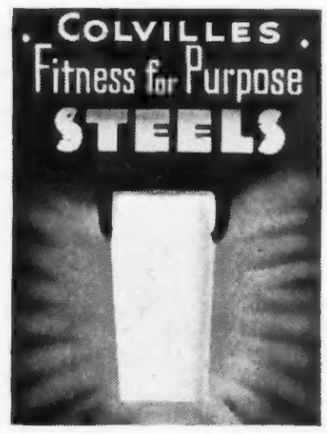


MADE IN ENGLAND

Perfect annealing with a lasting bright finish, and at less cost in many cases, than ordinary annealing, is now being obtained by G.E.C. Electric Furnaces for the Grünewald process.

The installation pictured above is at the Meadow Hall works, Sheffield, of Arthur Lee & Sons, Ltd. A G.E.C. vertical cylindrical type electric furnace of 88 kw. capacity, and 8 Grünewald annealing pots, each with an effective loading space 28″ dia. by 68″ deep.

COLVILLES "BIG FIVE"



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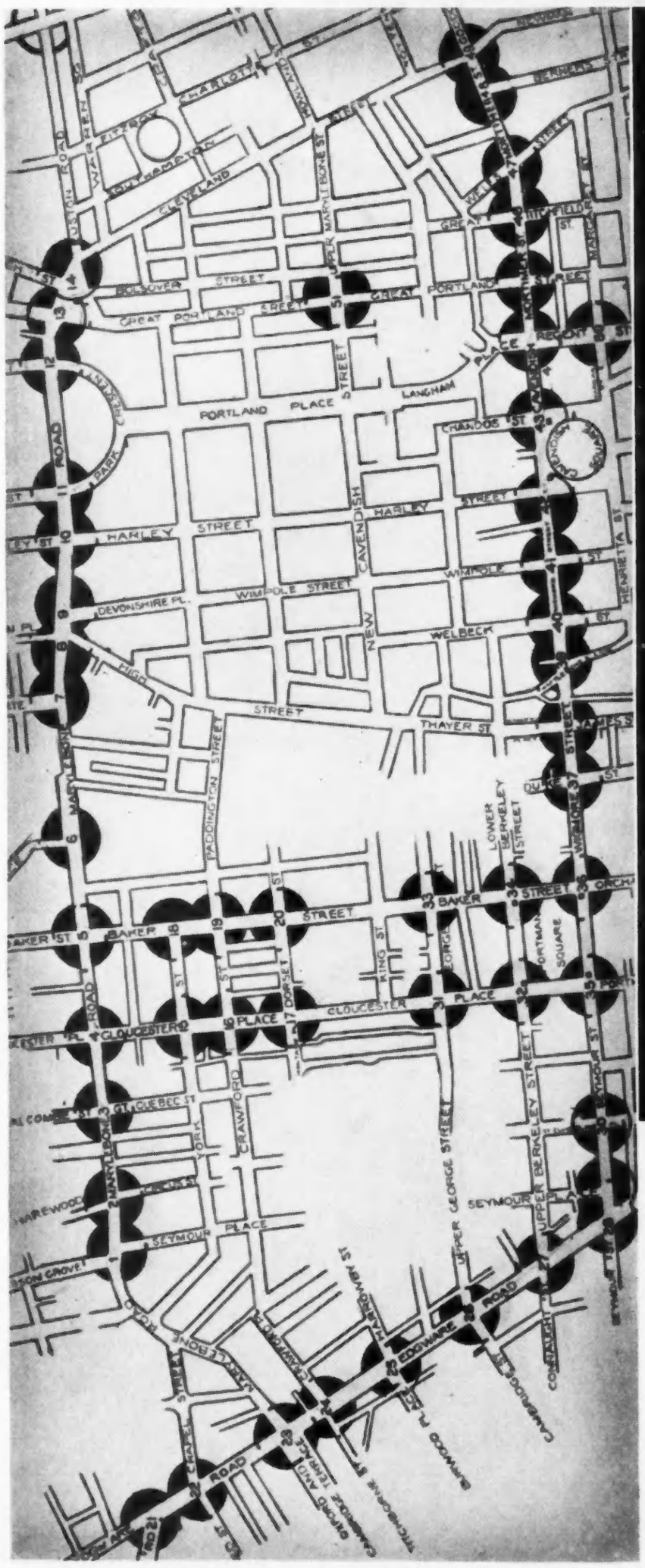

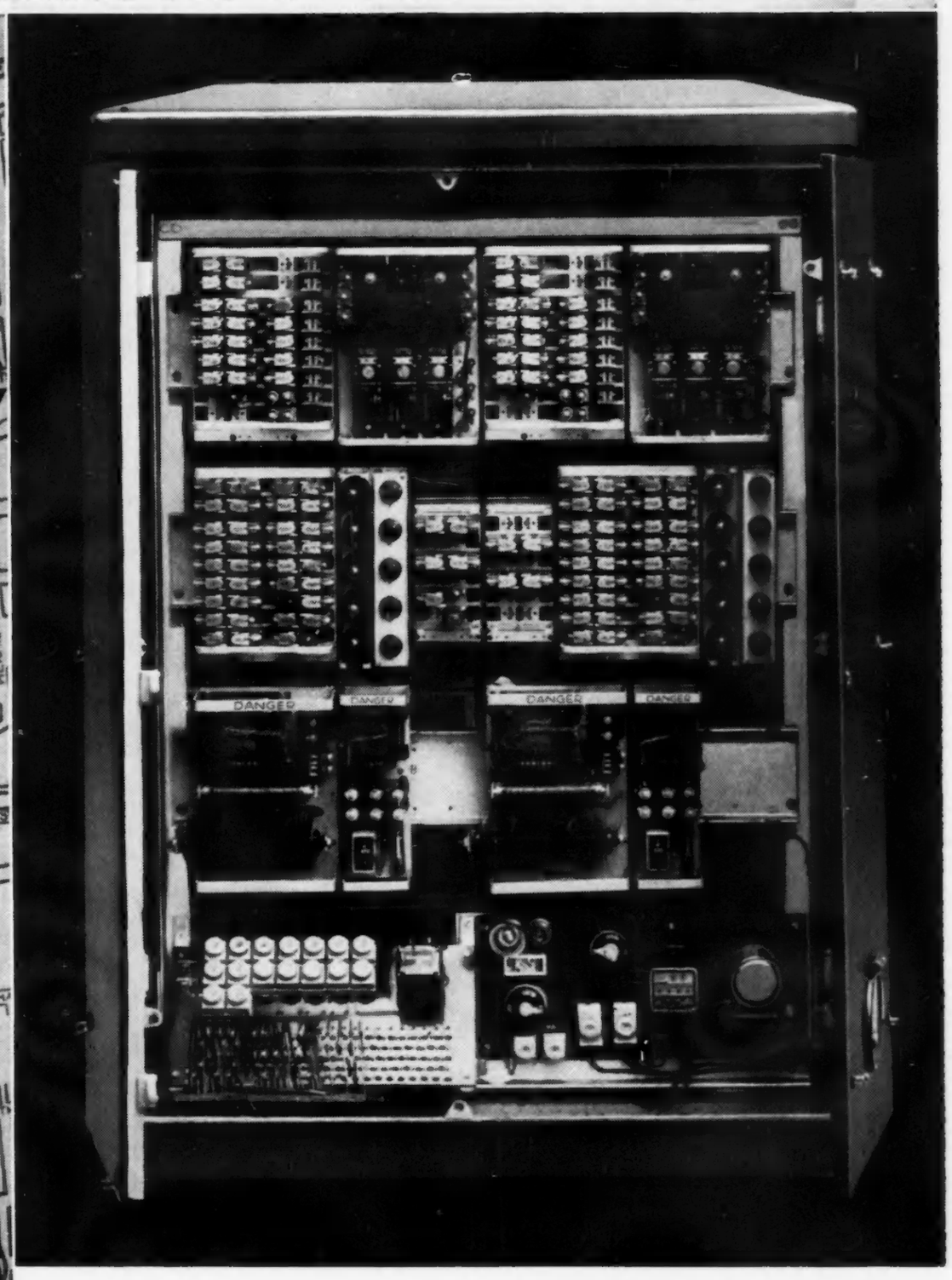

Dual Master controller and Traffic integrator.

Plan of streets in the Borough of St. Marylebone, showing the intersections covered by the AUTOFLEX traffic control system.

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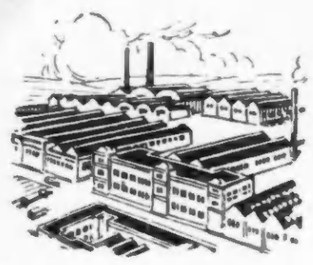

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